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Metropolitan District Commission

Water Supply Study and
Environmental Impact Report–2020

Task 8:
Merrimack River

Assessment Report

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Submitted To:
Metropolitan District Commission

By:
Wallace, Floyd, Associates Inc.

June, 1985

Metropolitan District Commission

Water Supply Study and
Environmental Impact Report-2020

TASK 8:
MERRIMACK RIVER: ASSESSMENT REPORT

Appendix to the Draft Environmental Impact Report

Submitted To:
Metropolitan District Commission

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FOREWORD

The Metropolitan District Commission (MDC) Water Supply Study and Environmental Impact Report (EIR) is a study of the forty-year water needs of the cities and towns served by the MDC Water Division and a report on the impacts anticipated from alternative means of meeting these needs. The alternatives being studied are: Demand Management, Connecticut River, Millers River and Tully River, Merrimack River, User Sources, Watershed Management, Upper Sudbury Watershed, Plymouth Aquifer, and No Action. Desalination was considered in Phase I and will be reported in the Environmental Impact Report.

This long-term water supply study was initiated in 1980 and is projected to be completed in 1986. Phase I of the study was completed in 1980 and involved a review of existing information and recommended methodologies to fill any gaps in the data and to perform the required analyses.

Phase II began in 1982 and involves these major steps:

- projecting water demands of current and potential future users of MDC water supplies to the year 2020;
- assessing the engineering, social, environmental, economic, and land use impacts of the nine alternatives being considered; and,
- recommending the Preferred Alternative(s) for meeting forecast water needs.

This report assesses the impacts of implementing the Merrimack River Alternative. It is one of nine individual assessment reports that are appendices to the Draft Environmental Impact Report. These assessment reports should be read with the companion summary report on assessment findings, which compares the impacts of all alternatives and describes the criteria for the selection of the Preferred Alternative(s). The Draft Environmental Impact Report (DEIR) will identify an alternative or combination of alternatives as the Preferred Alternative.

The DEIR (EOEA File #03518) is being prepared in accordance with regulations of the Massachusetts Environmental Policy Act (301 CMR 10) administered by the Executive Office of Environmental Affairs (EOEA) and is subject to public and agency review and comment as required by those regulations.

TABLE OF CONTENTS

Page	
i	FOREWARD
v	LIST OF TABLES
ix	LIST OF FIGURES
1	8.00 SUMMARY
9	8.10 ENGINEERING
79	8.20 WATER QUALITY
107	8.30 ECOLOGY
169	8.40 AIR QUALITY
181	8.41 NOISE
187	8.50 LAND USE
193	8.60 SOCIO-ECONOMIC IMPACTS
199	8.70 SIGNIFICANT CULTURAL RESOURCES
	APPENDICES

LIST OF TABLES

Tables	Page	
Table 8.11-1	13	Historic Flows, Merrimack River at Lowell - MGD
Table 8.11-2	14	Merrimack Transfer Potential Based on Treatment Plant Capacity of 200 MGD
Table 8.11-3	15	Merrimack Transfer Potential, Surplus for Month Based on Treatment Plant Capacity of 200 MGD
Table 8.11-4	16	Merrimack Transfer Potential, Days Pump/Month Based on Treatment Plant Capacity of 200 MGD
Table 8.11-5	17	Percent Reduction of Historic Flow, Merrimack River at Lowell, Due to MDC Pumping Using a 200 MGD Plant
Table 8.11-6	20	Potential Transfer Based on Treatment Plant Capacity of 235 MGD
Table 8.11-7	21	Actual Transfer Based on Treatment Plant Capacity of 235 MGD
Table 8.11-8	22	Potential Number of Days per Month that Merrimack Operates
Table 8.11-9	23	Actual Number of days per Month that Merrimack Operates
Table 8.11-10	24	Summary Output for Trial No. 1, Run KK-23
Table 8.11-11	28	Simulation of Flows in Merrimack River at Lowell Mean Daily Values for 50 Years
Table 8.11-12	30	Merrimack Transfers and Pawtucket Dam Power Loss, 235 MGD Treatment Plant
Table 8.11-13	32	Summary Output for Trial No. 1, Run HY-14
Table 8.11-14	33	Summary Output for Trial No. 2, Run HY-14
Table 8.11-15	34	Summary of Hydrologic Impacts Merrimack Alternative, Run HY-14
Table 8.11-16	36	Quabbin Reservoir, End of Month Storage - Percent of Net Storage
Table 8.11-17	38	Wachusett Reservoir, End of Month Storage - Percent of Net Storage
Table 8.11-18	39	Quabbin Reservoir, End of Month Elevation
Table 8.11-19	40	Wachusett Reservoir, End of Month Elevation

Tables	Page	
Table 8.11-20	41	Actual Transfer, Run HY-14
Table 8.11-21	46	Delta Values, Outflow from Quabbin Reservoir
Table 8.11-22	47	Delta Values, Streamflow - Chicopee River at Indian Orchard
Table 8.11-23	48	Delta Values, Streamflow - Connecticut River at Thompsonville, CT
Table 8.11-24	49	Delta Values, Outflow from Wachusett Reservoir
Table 8.11-25	50	Delta Values, Streamflow - Merrimack River at Pawtucket Dam
Table 8.11-26	51	Delta Values, Streamflow - Merrimack River at Lowell
Table 8.11-27	52	Delta Values, Streamflow - Merrimack River at Lawrence Dam
Table 8.12-1	54	Allied Water Resource Flow Needs Merrimack River at Lowell, Massachusetts
Table 8.12-2	55	Updated Allied Water Flow Needs Merrimack River at Lowell, Massachusetts
Table 8.12-3	63	Costs for the Merrimack River Alternative
Table 8.12-4	65	Land Acquisition and Easement Requirements, Merrimack River Alternative
Table 8.14-1	77	Merrimack River Alternative, Operation at 165 MGD
Table 8.14-2	78	Merrimack River Alternative, Operation at 200 MGD
Table 8.14-3	78	Merrimack River Alternative, Operation at 235 MGD
Table 8.21-1	80	Summary of Data Sources and Extent of Available Data Used in Baseline Water Quality Documentation of the Merrimack River
Table 8.21-2	83	Water Quality Parameters Analyzed
Table 8.21-3	86	Massachusetts Water Quality Standards for Class SB and B Waters
Table 8.21-4	87	Merrimack River Water Quality at Proposed MDC Diversion Location
Table 8.21-5	93	Major Municipal Wastewater Discharges
Table 8.21-6	95	Summary of Sediment Data for the Merrimack River

Tables	Page	
Table 8.21-7	98	Population for Massachusetts Towns in Years 1980, 1985, 1990, 1995, 2000, and 2020
Table 8.21-8	100	Allied Water Flow Needs Merrimack River at Lowell, Massachusetts
Table 8.31-1	115	Indicator Species Selected for the Merrimack River Aquatic Ecology Assessment
Table 8.31-2	118	Summary of Impacts of the Proposed Merrimack River Diversion on Macroinvertebrate and Fish Indicator Species
Table 8.33-1	132	Indicator Species Selected for the Merrimack River Floodplain Ecology Assessment
Table 8.33-2	136	Summary of Impacts of the Proposed Merrimack River Diversion on Floodplain Plant and Wildlife Indicator Species
Table 8.34-1	156	Indicator Species Selected for the Merrimack Tunnel R.O.W. Assessment
Table 8.34-2	160	Summary of Impacts of the Proposed Merrimack R.O.W. on Terrestrial Plant and Wildlife Indicator Species
Table 8.40-1	170	Annual Summary of Air Quality Data
Table 8.40-2	173	Heavy-Duty Construction Equipment Exhaust Emission Factors
Table 8.40-3	175	Estimates of Fugitive Dust Emissions from Construction
Table 8.40-4	176	Estimated Annual Power Plant Emissions from Electric Energy Demand
Table 8.40-5	178	Massachusetts and National Ambient Air Quality Standards
Table 8.50-1	187	Existing Land Use
Table 8.60-1	195	Summary of Impacts Associated with Merrimack River Alternatives
Table 8.60-2	197	Summary of Cost Implications Associated with Merrimack River

LIST OF FIGURES

Figures	Page	
Figure 8.00-1	2	Merrimack River Facilities and Tunnel Alignment
Figure 8.00-2	4	Merrimack River Water Treatment Plant Location
Figure 8.00-3	5	Merrimack River Facilities at Spot Pond
Figure 8.11-1	25	Drainage Affecting Merrimack River Flows at Lowell
Figure 8.11-2	37	Quabbin Reservoir Elevation
Figure 8.11-3	43	Connecticut River Streamflow at Thompsonville
Figure 8.11-4	44	Merrimack River Streamflow at Pawtucket Dam
Figure 8.11-5	45	Baseline and Merrimack River Streamflows at Pawtucket Dam
Figure 8.12-1	57	Safe Yield of MDC System with Merrimack River Alternative
Figure 8.12-2	67	Design, Procurement, and Construction Schedule
Figure 8.14-1	72	Hydropower Plants
Figure 8.21-1	81	Water Quality Stations on the Merrimack River Sampled by Previous Investigators and Sediment Chemistry Stations Sampled by NAI in 1982
Figure 8.21-2	90	Long Term Trend of Water Quality of Merrimack River at Lowell Water Intake
Figure 8.21-3	91	Long Term Trend of Water Quality of Merrimack River near West Newbury
Figure 8.21-4	92	Merrimack River Water Quality, Summer 1981
Figure 8.21-5	102	Historical Flow Rates in the Merrimack River near Lowell
Figure 8.21-6	103	Monthly Average Transfer and Monthly Frequency of Potential Withdrawal Based on a 50 Year Record, 1930-1979.
Figure 8.31-1	111	Benthic Macroinvertebrate and Fish Sampling Stations and Gear Types Used During the 1982 NAI Field Studies on the Merrimack River
Figure 8.33-1	122	Floodplain Community Stations on the Merrimack River Sampled by NAI in 1982
Figure 8.34-1	146	Terrestrial Community Stations in the Vicinity of the Merrimack Tunnel R.O.W. Sampled by NAI in 1982

8.00 SUMMARY

The Merrimack River Alternative involves the transfer of water from the Merrimack River to the MDC distribution system during periods of high flow in the river.

Water would be diverted through intake screens located in the river at Tyngsborough and pumped to a water treatment plant near the river. A deep tunnel would convey the water 26 miles by gravity to the vicinity of Spot Pond in Stoneham, where pumping would boost the pressure to a level sufficient to deliver the water into the MDC distribution system. Facilities at this end of the tunnel include an outlet to Spot Pond, connections to the Northern Low Service System and Fells Reservoir in the Middlesex Fells Reservation, and connection to Shaft 9A of the MDC distribution system in Medford. Figure 8.00-1 shows the location of the Merrimack River Alternative facilities and tunnel alignment.

The diversion of water from the Merrimack River is designed to occur only during periods of high flow in the river and when Quabbin and Wachusett Reservoirs are less than 98 percent full. Minimum streamflow requirements for migration of anadromous fish and effective dilution of wastewater discharges to the river have been incorporated in the design of the alternative as constraints in the yield analysis. The potential loss of hydropower production at hydropower facilities in Lowell and Lawrence as a result of diverting water is an impact of implementing this alternative.

The computer simulations of the MDC system safe yield with the Merrimack River Alternative indicate that the forecast MDC water need for the year 2020 of 120 MGD could be met with this alternative alone. Thus, the alternative was sized to provide an average annual yield of 120 MGD. Due to low flow in the river, there would be very few days during the months of July, August, September, and October on which diversion could be made and minimum streamflow requirements still be met. Therefore, the diversion period was limited to eight months, November through June. During this eight-month period, diversion is only permitted when Merrimack streamflow exceeds the minimum flows required for anadromous fish and wastewater dilution and when Quabbin and Wachusett Reservoirs are less than 98 percent full. On average, there are 186 days per year on which all of the above constraints are satisfied. To provide an average annual yield of 120 MGD, the capacities of the water treatment and pumping facilities are designed for a capacity of 235 MGD.

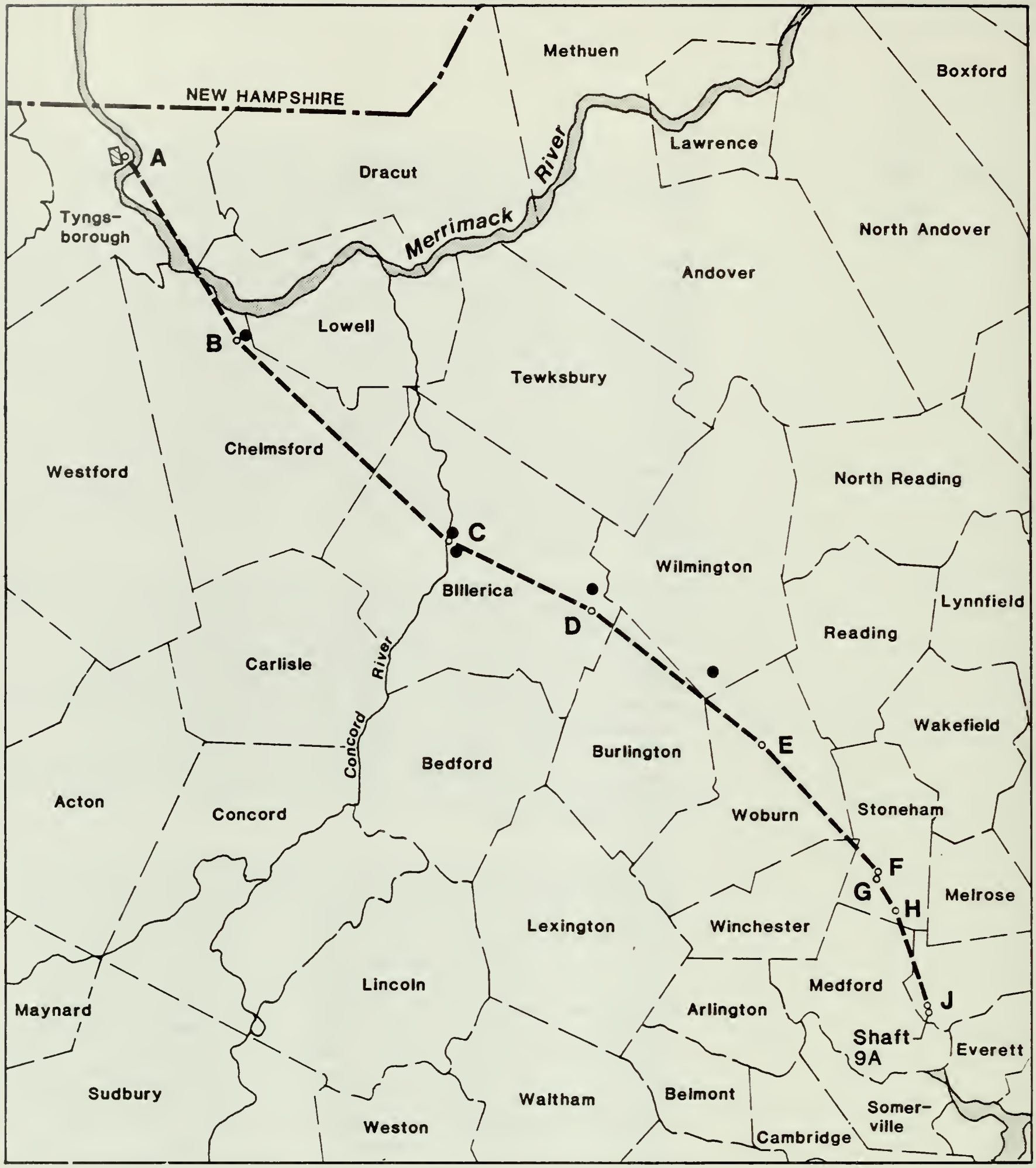


Figure 8.00-1.
Merrimack River Facilities and Tunnel Alignment

Prior to the year 2020, this Water Treatment Plant (WTP), if implemented, would run at less than full capacity. Therefore, the WTP would be constucted in three stages. In year 1990, the alternative is designed for a throughput of 165 MGD and a yield of 86 MGD. By year 2006, a 35 MGD expansion is needed to increase the yield to 104 MGD. Finally, by year 2013, the remaining 35 MGD of capacity will be constructed. The year 2020 safe yield of the MDC system with the Merrimack Alternative fully operational would be 420 MGD. This is the only alternative under study which alone could satisfy the entire projected MDC water need.

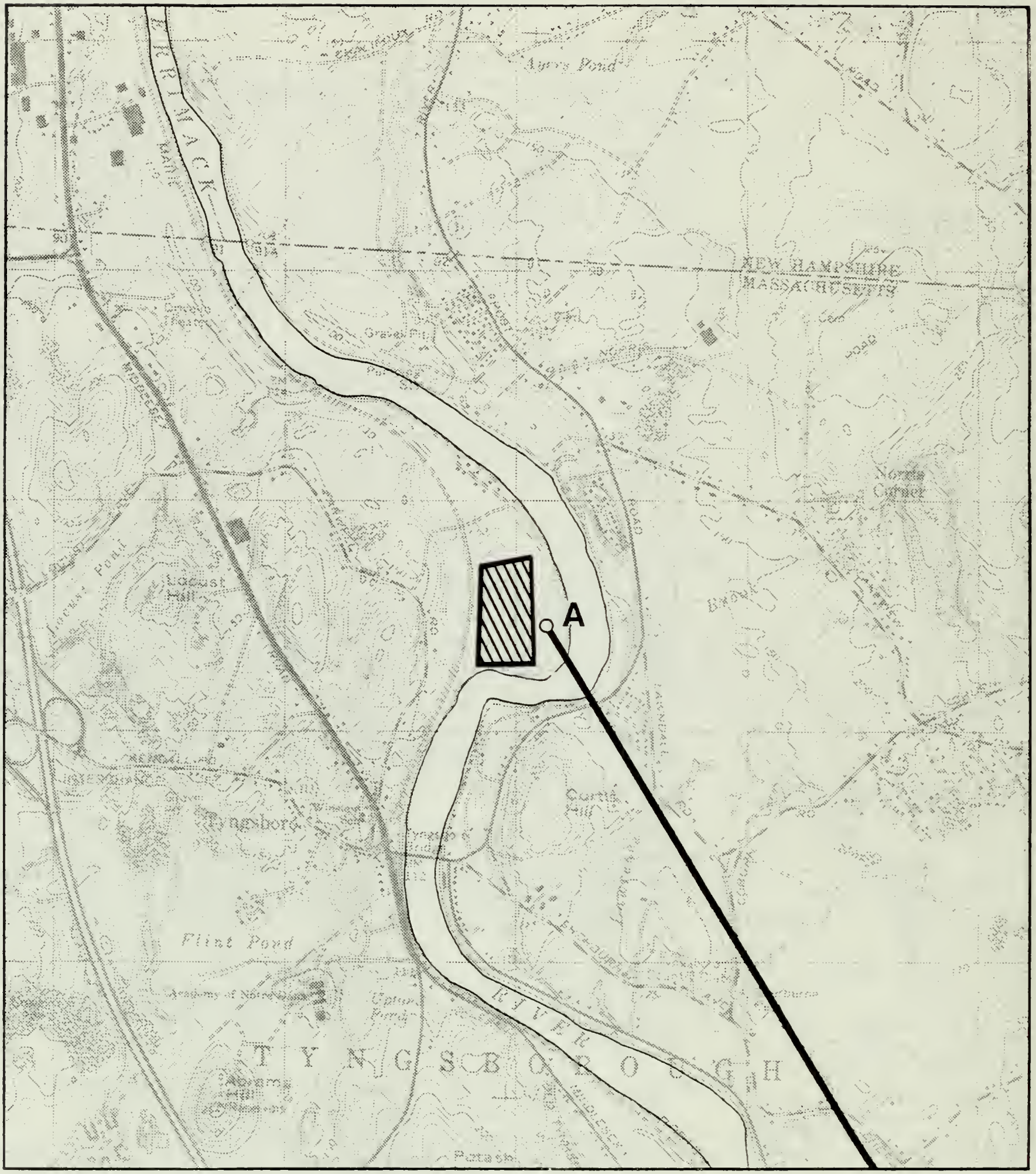
Diversion facilities at the Merrimack River and location of shafts are shown in Figures 8.00-2 and 8.00-3. Facilities include an intake structure and pumping station, a water treatment plant, approximately 26 miles of tunnel from the Merrimack River to MDC shaft 9A, nine shafts, and a pumping facility and outlet structure at Spot Pond.

The land area required for the water treatment plant and intake is approximately 35 acres. The WTP location studied is privately owned farm land. The land area permanently disturbed by the shafts and spoil piles between the water treatment plant and Spot Pond is approximately 68 acres. The facilities at Spot Pond and Shafts F, G, and H are within the boundaries of the Middlesex Fells Reservation. The buildings at Spot Pond would require 1.5 acres. Shaft J adjacent to the MDC Shaft 9A would require 0.5 acre. In addition, 150 acres of land will be required for a sludge disposal landfill to serve the WTP. The identification of a specific disposal site is not part of this study.

The quality of the Merrimack River water to be diverted requires treatment processes which include conventional treatment to control turbidity, iron, manganese, and trace metal concentrations, and advanced treatment (activated carbon) for removal of phenols, PCB, and toxic organics.

Order-of-magnitude capital and operating and maintenance cost estimates were developed for this alternative. The estimated accuracy of the order-of-magnitude cost estimates is ±30 percent. All costs are on a July 1982 basis.

Capital costs include construction costs; contingency; contractor's overhead and profit; engineering and construction management fees; land acquisition and right-of-way costs; legal, fiscal, and administrative fees; and interest during construction. The total capital cost is estimated to be $501,100,000 for the Merrimack River Alternative. Approximately 60 percent of this cost is for the tunnels and shafts. Approximately 35 percent is for the water treatment plant and sludge disposal landfill.



Legend

- Proposed Tunnel
- ○A Tunnel Shaft
- Water Treatment Plant

Figure 8.00-2.
Merrimack River Water Treatment Plant Location

0 25000'

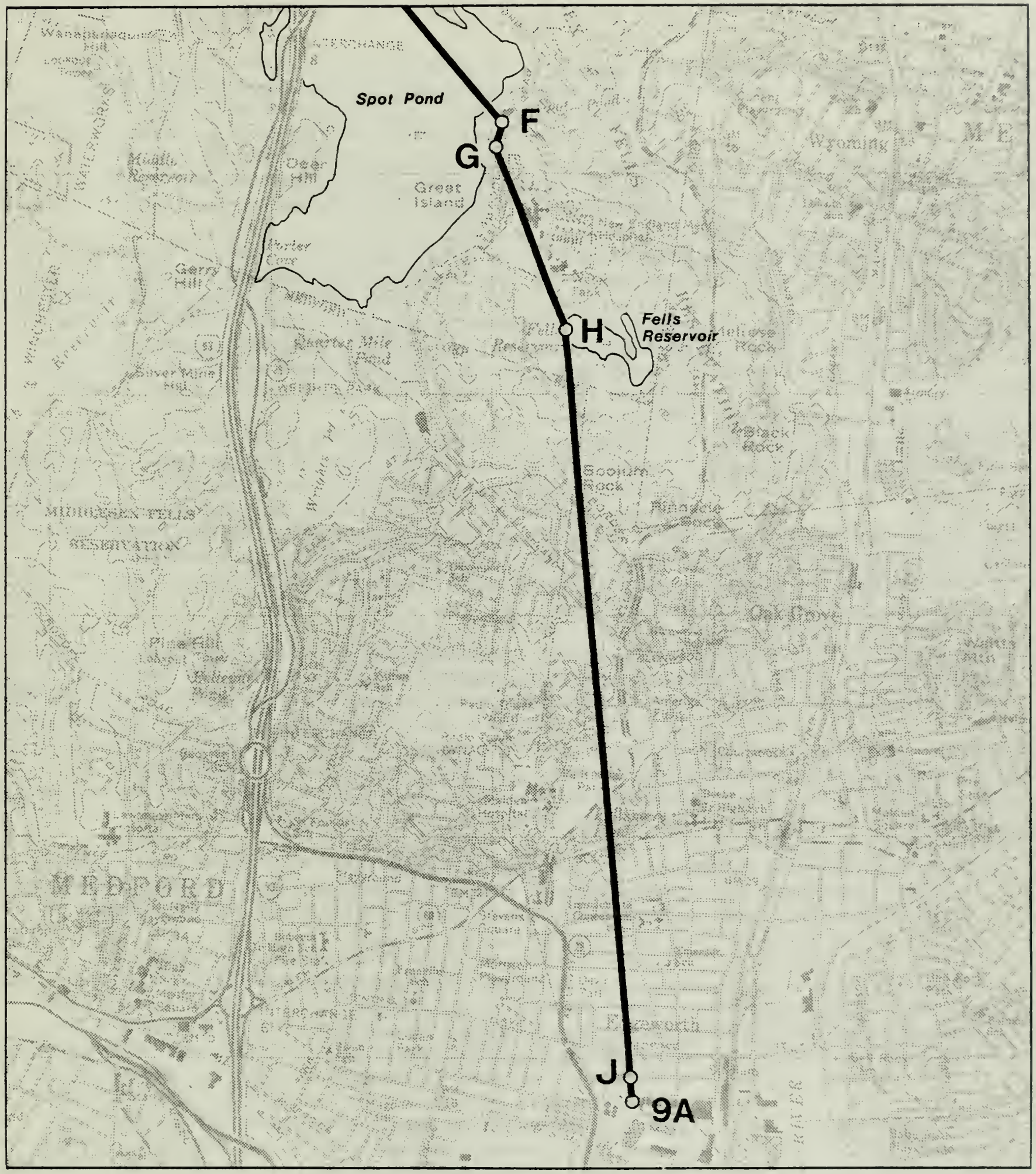


Figure 8.00-3.
Merrimack River Facilities at Spot Pond

Operating and maintenance costs include costs of energy, labor and consumable items (including materials and chemicals) required to operate and maintain the facilities. The total annual operating and maintenance cost of this alternative is estimated to be $14,599,000 per year. Approximately 40 percent of this cost is for energy required by the pumping and treatment facilities.

The net present value of each water supply alternative has been determined as a basis of comparison between alternatives. The Merrimack River Alternative provides the MDC with an additional 120 MGD of safe yield at a net present value cost of $567 per million gallons if the project is constructed in one phase and $498 per million gallons if the project is constructed in three phases.

The effect of implementation of this alternative on the wholesale water rate of the MDC if the impacts are spread across all MDC users is to increase the present wholesale rate by approximately 102 percent in the early years (1990 to 1994) and increased by 35 percent in the later years (2010 to 2014). The average retail rate increase is estimated to be from 18 percent in the early years to 6 percent later on.

The operation of the alternative will result in an impact on the MDC hydropower facilities and on the private hydropower facilities on the Merrimack River at Lowell and Lawrence. Analysis indicates that there will be a decrease in hydroelectric production at the Eldred L. Field Hydroelectric Plant at Lowell and the Lawrence Hydroelectric Plant. In addition, there will be an overall decrease in MDC hydropower production.

Construction impact areas for the alternative include permanent and temporary features: spoil piles, shafts, and construction staging areas along the rights-of-way.

In the vicinity of Spot Pond and the Middlesex Fells Reservation where shaft pumping facilities will be constructed, there is historical record of the bur-reed (Sparganium minimum), a species of special concern in Massachusetts. At Shaft H there are records of occurrence for several species of special concern in Massachusetts: one historical and one current record for two salamander species; swainson's thrush, were observed in the study area; and a rare amphipod is known to occur in the area. Thorough searches of the vicinity of these sites to assess the likelihood and extent of project impacts to these species are recommended if this alternative is selected.

The construction of the facilities required can be expected to result in increases in fugitive dust. Additional

emissions of carbon monoxide, nitrogen oxides, hydrocarbons and particulates also can be expected from the exhausts of construction equipment used.

Construction of the shafts is expected to generate noise and some ground vibrations. Boring of the deep tunnel is not expected to generate more than barely perceptible ground rumblings. Warning residents of unusual sporadic noises or ground vibrations due to blasting is generally the method used to mitigate these impacts.

During the construction period for Shaft J, there would be substantial truck traffic in the densely developed residential neighborhood, near Shaft #9A in Malden.

If this alternative is part of the Preferred Alternative, direct employment at both the local and regional levels during the design and construction period is expected to increase moderately.

It is not possible at this time to predict the effects of the construction upon cultural resources because of lack of adequate knowledge about the location and significance of prehistoric and historical cultural resources at the proposed facility sites. However, considering that a deep tunnel would be constructed and most of the spoil sites are located in areas extensively disturbed by gravel pitting, only a limited impact on cultural resources is expected.

The ecological impacts of changes in river water level due to the diversion were also assessed. No significant short or long-term impacts to floodplain or river channel plant or wildlife communities, indicator species, or species of special interest are expected to occur as a result of the proposed transfer. However, impingement of migratory and resident sport fish species on intake screens and entrainment have the potential for locally affecting aquatic communities and species populations.

The noise generated by the operation of water diversion facilities is not expected to be significant. Basic noise control measures will be incorporated in building design. However, sludge removal trucks may generate noise impacts in noise sensitive areas along the haul route.

Long-term impacts on air quality can be expected to arise from the combustion of fossil fuels burned at off-site power generating stations to supply the electrical energy demands of the new facilities. The significance of this impact cannot be evaluated due to the uncertainty of the location and mix of power plant fuel consumption.

Direct land use for the Merrimack River Alternative will result in a very small change to overall community land use patterns, although the land considered in the conceptual design of the water treatment plant is in active agricultural use. Direct land use impacts for the Merrimack River Alternative are considered significant due to the estimated truck traffic associated with sludge removal from the water treatment plant.

River water quality impacts associated with operation of the alternative were assessed. The water quality impact assessment indicates that the proposed diversion regime with incorporated streamflow constraints will not result in substantial water quality changes in the river downstream of the diversion point.

8.10 ENGINEERING

The following chapter discusses the results of the safe yield analyses of the existing system with the Merrimack River Alternative, the conceptual design of the alternative, the streamflow impacts, and potential impacts on hydropower production.

8.11 HYDROLOGIC MODELING

Potential Transfer Volumes

The potential transfers for the Merrimack Alternative are the monthly volumes of water that could be transferred to the MDC system subject only to two constraints:

- flow in the Merrimack River in excess of designated minimum values,
- capacity of the treatment plant and delivery system.

The HYDA model was used to estimate the potential transfers. As input, the model uses historic daily flow data for water years 1930 to 1979 obtained from a USGS magnetic tape. Each day's flow at the USGS gaging station on the Merrimack River at Lowell (located a short distance downstream from the confluence with the Concord River) was compared to values below which no transfers would be allowed. These values change monthly. For days in which the flow exceeded the minimum, the excess was considered to be a potential transfer, but only up to the capacity of the treatment plant. The daily potential transfers were aggregated monthly, and these monthly values became new input data files for use in the safe yield model.

The minimum flow criteria and the historic mean flow for USGS gaging station 01100000, Merrimack River at Lowell, for the period 1930 to 1979 are:

Month	Minimum Flow Criteria-cfs	Historic Mean Flow-cfs
Oct	3500	3746
Nov	3500	5873
Dec	2000	7099
Jan	2000	7031
Feb	2000	7238
Mar	6000	12846
Apr	6000	19726
May	4000	11723
Jun	4000	6083
Jul	3500	3254
Aug	3500	2626
Sep	3500	3048
Mean	3625	7514

The minimum flow criteria are the values given in the NEWS study (January 1977) without consideration of the hydroelectric power component. As such, the values apply only to the "Anadromous Fish Restoration Program" criteria.

The mean monthly historic flows in million gallons per day are shown in Table 8.11-1. The flows are subject to regulation in Wachusett and Sudbury Reservoirs, Lake Cochituate, by powerplants, by Franklin Falls Reservoir since 1942, and by Squam, Newfound, Winnipesaukee, Winnisquam and other lakes and reservoirs upstream.

The HYDA program generates several parameters for each designated water treatment plant size:

- Potential transfer -- MGD per month
- Surplus or excess -- MGD per month (additional volumes that could be transferred if not subject to the treatment plant capacity)
- Number of days per month that the treatment plant could operate.
- Percentage of reduction in the historic flow at Lowell if the potential transfer were withdrawn.

The values of these parameters, for a treatment plant capacity of 200 MGD, are shown in Tables 8.11-2, 3, 4, and 5.

Safe Yield

The potential transfer data for each treatment plant size are used as input to the safe yield model, MDC003. The model is run for the existing water supply system (without Sudbury) and with the Merrimack alternative active. At the start of each month, the model establishes a total system demand equal to the trial yield modified for seasonal variations. The withdrawals for the western areas (e.g., Chicopee) are subtracted, giving the demand for the Boston area. The latter is then reduced by the value of the Merrimack potential transfer, creating a new value for the Boston demand to be supplied from Quabbin and Wachusett Reservoirs. The model then simulates the Quabbin/Wachusett part of the system in the normal manner.

The Merrimack potential transfers, PT(9), can be controlled in two ways:

- selected months can be designated in which no transfers are to be made, and
- the transfer can be eliminated during any month in which the combined storage in Quabbin and Wachusett exceed a designated percentage of their full capacity.

Table 8.11-1

HISTORIC FLOWS, MERRIMACK RIVER AT LOWELL - MGD

IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	1143.	1456.	1374.	2790.	3143.	7512.	6809.	3883.	3368.	1507.	1480.	1012.	2953.
2	1931	862.	1914.	1559.	1185.	1360.	5038.	11445.	6053.	6955.	2218.	1494.	1356.	3449.
3	1932	1367.	1860.	3036.	5837.	4263.	4502.	14385.	4371.	1550.	1545.	1367.	2134.	3836.
4	1933	4029.	7651.	3669.	4248.	4154.	7803.	22634.	7179.	2542.	1162.	1474.	2575.	5739.
5	1934	3226.	2662.	2730.	3595.	2468.	7020.	18513.	6707.	2672.	1228.	1087.	2387.	4519.
6	1935	2717.	3685.	4119.	6999.	4697.	8935.	9787.	5563.	6424.	3215.	1425.	1773.	4942.
7	1936	1275.	2111.	2726.	4162.	2975.	29588.	13395.	5009.	1992.	1321.	1021.	1193.	5595.
8	1937	2310.	2330.	6916.	7694.	6878.	5511.	11078.	12987.	5496.	2478.	1649.	1514.	5564.
9	1938	2262.	6147.	7678.	6060.	7067.	7147.	8482.	4929.	3360.	5695.	4878.	12700.	6347.
10	1939	5096.	4231.	9744.	4791.	3934.	6928.	17091.	7879.	2717.	1455.	1507.	1116.	5546.
11	1940	1169.	2296.	2052.	1516.	1559.	2671.	18397.	12207.	6780.	2543.	1449.	1908.	4539.
12	1941	1214.	3872.	3259.	3920.	5143.	3764.	6582.	2645.	1569.	1604.	921.	808.	2921.
13	1942	1006.	1547.	1660.	2211.	1817.	9252.	9716.	4183.	4441.	2159.	1688.	1304.	3419.
14	1943	1577.	3523.	4479.	3450.	3774.	8025.	8921.	11715.	4001.	1827.	3100.	1684.	4682.
15	1944	2323.	5874.	2847.	1743.	2014.	4808.	12177.	6457.	6371.	2909.	1256.	2535.	4268.
16	1945	2176.	2271.	4168.	4415.	3780.	13294.	9597.	12205.	7410.	4123.	2309.	1778.	5646.
17	1946	2758.	3909.	6507.	5710.	4631.	12428.	6396.	7671.	5517.	1742.	2702.	1838.	5163.
18	1947	3423.	2625.	2566.	3187.	5577.	8139.	11123.	8789.	6531.	2690.	1655.	1500.	4804.
19	1948	813.	2522.	1731.	1490.	2300.	10161.	8906.	9383.	6715.	2848.	1486.	905.	4113.
20	1949	883.	2759.	1916.	6181.	4836.	6446.	7503.	4531.	1910.	1032.	909.	1254.	3334.
21	1950	1124.	1848.	2315.	3973.	3593.	5538.	11890.	4728.	3132.	954.	834.	1187.	3413.
22	1951	1295.	3909.	6593.	4535.	8928.	9061.	17158.	5778.	3722.	2999.	3097.	2781.	5784.
23	1952	3622.	10160.	6650.	8705.	8117.	8071.	17933.	9023.	6885.	1558.	1556.	1299.	6932.
24	1953	1414.	1381.	4803.	5187.	8787.	16303.	17492.	11001.	2176.	1104.	1267.	854.	5963.
25	1954	1156.	2446.	5808.	3034.	5057.	7429.	10621.	16008.	6190.	2353.	1775.	9355.	5930.
26	1955	4094.	7823.	9319.	5540.	4819.	7553.	11216.	5153.	4290.	1432.	3376.	2208.	5566.
27	1956	4777.	8825.	3128.	8268.	4734.	5145.	16228.	11205.	4900.	2418.	1132.	1937.	6048.
28	1957	2030.	2360.	3967.	4517.	3764.	6142.	6080.	3097.	1547.	1253.	774.	579.	3007.
29	1958	833.	2899.	7583.	7241.	6472.	7947.	17005.	9964.	2762.	1576.	1377.	1261.	5565.
30	1959	1749.	2542.	2856.	2750.	2904.	6285.	14223.	3976.	2437.	2169.	1196.	1698.	3723.
31	1960	4707.	7269.	8827.	5682.	6450.	4850.	21527.	8938.	4386.	1615.	1633.	3775.	6611.
32	1961	3436.	4388.	3601.	2345.	3113.	7749.	13971.	7965.	3442.	1805.	1227.	1692.	4559.
33	1962	1564.	2359.	2381.	3265.	2204.	5340.	14896.	6297.	2322.	1137.	1335.	1090.	3679.
34	1963	6155.	6877.	6672.	3664.	3145.	6661.	12182.	6011.	1657.	888.	826.	761.	4629.
35	1964	845.	4051.	4337.	5093.	4949.	8320.	11651.	4153.	1180.	959.	742.	685.	3900.
36	1965	669.	1191.	1850.	1636.	2126.	3788.	5684.	3229.	1466.	750.	582.	881.	1983.
37	1966	1398.	1720.	1630.	1670.	2700.	7115.	6024.	5288.	2435.	771.	888.	1236.	2739.
38	1967	1993.	4337.	2996.	2573.	2477.	3474.	15135.	10308.	4767.	2826.	1944.	1114.	4492.
39	1968	1889.	2447.	4408.	2922.	3247.	11229.	9219.	6655.	7586.	3879.	1195.	1071.	4652.
40	1969	1251.	2940.	6357.	3402.	3625.	6968.	21368.	9002.	3148.	1616.	3739.	1744.	5424.
41	1970	1327.	7290.	7655.	6072.	11890.	6505.	15316.	7632.	2490.	1447.	1010.	1093.	5752.
42	1971	1999.	2751.	3212.	2695.	3384.	6362.	14025.	10672.	2269.	1013.	1363.	1340.	4255.
43	1972	1386.	1478.	3109.	3342.	3900.	9906.	14635.	12395.	6593.	4439.	1904.	1416.	5380.
44	1973	1971.	6231.	8064.	8472.	10412.	12894.	14433.	10696.	5433.	9382.	2646.	1379.	7654.
45	1974	1657.	2887.	12201.	8273.	6993.	8292.	11899.	9062.	3645.	1643.	897.	1986.	5784.
46	1975	2413.	3528.	5745.	5299.	5142.	9208.	11852.	5258.	3671.	2236.	1256.	2838.	4862.
47	1976	7280.	8725.	6525.	5713.	10157.	11619.	11638.	7981.	2205.	1692.	6534.	3176.	6916.
48	1977	6080.	2884.	2378.	1792.	1975.	13982.	13502.	5196.	2432.	1255.	1084.	1791.	4543.
49	1978	8230.	5747.	8023.	11974.	8226.	6257.	13879.	8482.	4730.	1258.	1108.	802.	6549.
50	1979	1095.	1253.	1687.	6410.	4256.	16162.	11858.	9334.	4367.	1428.	1705.	2181.	5155.
	AVER	2421.	3796.	4588.	4545.	4678.	8303.	12750.	7577.	3932.	2103.	1697.	1970.	4857.

Table 8.11-2

MERRIMACK TRANSFER POTENTIAL, MGD PER MONTH BASED ON TREATMENT PLANT CAPACITY OF 200. MGD

	QMERT=	3500.	3500.	2000.	2000.	2000.	6000.	6000.	4000.	4000.	3500.	3500.	3500.	CFS
IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	6.	33.	83.	188.	171.	187.	174.	192.	135.	0.	19.	0.	99.
2	1931	0.	60.	138.	63.	71.	81.	200.	200.	194.	53.	11.	9.	90.
3	1932	6.	37.	170.	200.	200.	117.	200.	159.	7.	19.	0.	51.	97.
4	1933	123.	200.	200.	200.	200.	196.	200.	194.	67.	0.	26.	87.	141.
5	1934	165.	144.	188.	200.	195.	174.	200.	194.	82.	6.	0.	84.	136.
6	1935	154.	195.	200.	200.	200.	200.	200.	192.	200.	148.	0.	61.	162.
7	1936	1.	74.	175.	194.	200.	135.	200.	177.	28.	0.	0.	0.	98.
8	1937	77.	91.	193.	200.	200.	155.	200.	200.	200.	90.	20.	0.	135.
9	1938	61.	157.	200.	200.	200.	193.	200.	195.	146.	189.	194.	147.	173.
10	1939	200.	200.	200.	200.	200.	200.	200.	200.	108.	26.	0.	0.	144.
11	1940	6.	73.	142.	114.	96.	9.	200.	200.	185.	145.	13.	49.	103.
12	1941	0.	147.	200.	200.	200.	47.	168.	99.	6.	46.	0.	0.	92.
13	1942	0.	36.	98.	173.	158.	178.	200.	180.	102.	86.	20.	5.	103.
14	1943	20.	179.	194.	198.	200.	192.	200.	200.	175.	25.	144.	33.	146.
15	1944	77.	191.	181.	161.	181.	110.	200.	194.	89.	117.	0.	64.	130.
16	1945	76.	103.	200.	200.	200.	200.	200.	200.	200.	194.	86.	33.	158.
17	1946	140.	144.	200.	200.	200.	191.	184.	200.	156.	25.	128.	32.	150.
18	1947	145.	145.	194.	194.	200.	187.	200.	200.	200.	95.	9.	13.	148.
19	1948	0.	95.	156.	127.	163.	97.	200.	200.	200.	154.	5.	0.	116.
20	1949	0.	89.	161.	200.	200.	181.	200.	179.	33.	0.	0.	16.	104.
21	1950	0.	36.	173.	200.	200.	110.	200.	178.	87.	0.	0.	0.	98.
22	1951	6.	76.	200.	200.	200.	200.	200.	200.	159.	147.	174.	138.	158.
23	1952	162.	200.	200.	200.	200.	200.	200.	200.	148.	4.	40.	0.	146.
24	1953	6.	27.	188.	196.	200.	200.	200.	200.	52.	0.	14.	0.	107.
25	1954	19.	67.	200.	200.	200.	200.	200.	200.	187.	71.	43.	200.	148.
26	1955	200.	200.	200.	200.	200.	200.	200.	170.	188.	5.	110.	79.	162.
27	1956	147.	200.	193.	181.	200.	191.	194.	200.	122.	80.	0.	53.	146.
28	1957	35.	60.	200.	200.	200.	200.	191.	130.	2.	13.	0.	0.	102.
29	1958	0.	122.	200.	200.	200.	200.	200.	200.	91.	26.	9.	0.	120.
30	1959	29.	113.	194.	178.	200.	169.	200.	163.	87.	60.	0.	40.	119.
31	1960	91.	200.	200.	200.	200.	187.	200.	200.	161.	0.	19.	127.	148.
32	1961	118.	200.	200.	200.	200.	200.	200.	200.	155.	11.	0.	52.	144.
33	1962	0.	72.	200.	200.	195.	116.	200.	200.	82.	0.	0.	0.	105.
34	1963	168.	200.	200.	200.	200.	139.	200.	200.	11.	0.	0.	0.	126.
35	1964	0.	153.	200.	200.	200.	180.	200.	165.	0.	0.	0.	0.	108.
36	1965	0.	27.	103.	93.	136.	63.	127.	133.	8.	0.	0.	0.	57.
37	1966	17.	38.	135.	143.	179.	189.	200.	200.	74.	0.	0.	19.	99.
38	1967	54.	173.	200.	200.	200.	60.	200.	200.	200.	167.	35.	0.	140.
39	1968	28.	83.	200.	200.	200.	90.	200.	200.	200.	135.	0.	0.	128.
40	1969	0.	133.	200.	200.	200.	124.	200.	200.	136.	13.	123.	33.	130.
41	1970	0.	178.	200.	200.	200.	200.	200.	200.	80.	0.	0.	0.	121.
42	1971	39.	111.	200.	200.	200.	200.	200.	200.	69.	0.	5.	0.	118.
43	1972	13.	0.	200.	200.	200.	194.	200.	200.	200.	200.	38.	0.	137.
44	1973	49.	200.	200.	200.	200.	200.	200.	200.	200.	170.	88.	7.	159.
45	1974	6.	109.	200.	200.	200.	200.	200.	200.	129.	35.	0.	66.	128.
46	1975	80.	166.	200.	200.	200.	200.	200.	174.	111.	72.	13.	47.	138.
47	1976	187.	200.	200.	200.	200.	200.	200.	200.	67.	7.	181.	153.	166.
48	1977	184.	115.	194.	183.	186.	200.	200.	174.	65.	6.	0.	60.	130.
49	1978	200.	200.	200.	200.	200.	123.	200.	200.	178.	0.	0.	0.	141.
50	1979	0.	0.	158.	194.	200.	200.	200.	200.	107.	6.	29.	57.	112.
	AVER	62.	121.	184.	188.	191.	163.	197.	189.	117.	53.	32.	36.	127.

AVERAGE DAILY YIELD (50 YRS) = 127. MGD

Table 8.11-3

MERRIMACK TRANSFER POTENTIAL, SURPLUS FOR MONTH BASED ON TREATMENT PLANT CAPACITY OF 200. MGD

	QMERT=	3500.	3500.	2000.	2000.	2000.	6000.	6000.	4000.	4000.	3500.	3500.	3500.	CFS
IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	7.	49.	150.	1319.	1724.	3480.	2777.	1112.	813.	0.	63.	0.	952.
2	1931	0.	268.	222.	43.	172.	1624.	7367.	3267.	4176.	200.	14.	2.	1440.
3	1932	33.	21.	1646.	4345.	2771.	775.	10307.	1682.	3.	39.	0.	572.	1832.
4	1933	1817.	5189.	2177.	2755.	2661.	3729.	18556.	4402.	272.	0.	74.	671.	3503.
5	1934	833.	328.	1254.	2102.	980.	3157.	14435.	3945.	228.	14.	0.	626.	2319.
6	1935	365.	1228.	2627.	5506.	3205.	4857.	5709.	2786.	3639.	911.	0.	64.	2569.
7	1936	0.	297.	1315.	2699.	1482.	25749.	9317.	2286.	7.	0.	0.	0.	3626.
8	1937	538.	341.	5432.	6201.	5385.	1636.	7000.	10202.	2710.	423.	8.	0.	3315.
9	1938	660.	3868.	6185.	4568.	5575.	3089.	4404.	2149.	704.	3246.	2422.	10394.	3915.
10	1939	2634.	1769.	8251.	3298.	2442.	2850.	13013.	5094.	167.	24.	0.	0.	3297.
11	1940	16.	392.	701.	243.	247.	87.	14319.	9422.	4023.	306.	22.	142.	2487.
12	1941	0.	1643.	1766.	2428.	3650.	282.	2607.	333.	0.	66.	0.	0.	1043.
13	1942	0.	103.	437.	803.	395.	5407.	5638.	1451.	2036.	196.	40.	0.	1377.
14	1943	27.	1174.	2992.	1960.	2281.	3955.	4843.	8930.	1311.	75.	825.	92.	2378.
15	1944	538.	3442.	1386.	325.	570.	1489.	8099.	3698.	4147.	727.	0.	856.	2097.
16	1945	204.	202.	2675.	2923.	2287.	9216.	5519.	9420.	4625.	1693.	302.	73.	3277.
17	1946	470.	1670.	5015.	4217.	3139.	8375.	2344.	4886.	2906.	61.	525.	35.	2813.
18	1947	1141.	363.	1079.	1705.	4085.	4107.	7045.	6004.	3745.	497.	21.	6.	2467.
19	1948	0.	734.	359.	141.	896.	6855.	4828.	6597.	3930.	584.	0.	0.	2083.
20	1949	0.	768.	513.	4689.	3343.	2424.	3425.	1824.	134.	0.	0.	13.	1416.
21	1950	0.	49.	902.	2480.	2100.	2012.	7812.	2024.	939.	0.	0.	0.	1514.
22	1951	1.	2100.	5101.	3042.	7435.	4983.	13080.	2992.	1103.	681.	704.	539.	3440.
23	1952	1280.	7698.	5158.	7213.	6624.	3993.	13855.	6237.	4256.	0.	48.	0.	4662.
24	1953	10.	145.	3330.	3699.	7294.	12225.	13414.	8215.	240.	0.	39.	0.	4031.
25	1954	47.	658.	4315.	1541.	3564.	3351.	6543.	13223.	3458.	458.	74.	6893.	3670.
26	1955	1632.	5361.	7827.	4047.	3326.	3476.	7138.	2402.	1526.	0.	1508.	204.	3199.
27	1956	2503.	6363.	1642.	6811.	3241.	1077.	12155.	8420.	2432.	473.	0.	193.	3764.
28	1957	79.	416.	2474.	3024.	2271.	2064.	2024.	501.	0.	5.	0.	0.	1067.
29	1958	0.	651.	6090.	5748.	4979.	3869.	12927.	7179.	509.	53.	12.	0.	3489.
30	1959	79.	259.	1370.	1294.	1411.	2418.	10145.	1315.	245.	296.	0.	157.	1572.
31	1960	2735.	4807.	7334.	4190.	4957.	801.	17449.	6153.	1662.	0.	55.	1865.	4306.
32	1961	1194.	1926.	2109.	852.	1620.	3671.	9893.	5180.	738.	1.	0.	74.	2267.
33	1962	0.	364.	888.	1773.	716.	1880.	10818.	3512.	209.	0.	0.	0.	1675.
34	1963	3816.	4415.	5179.	2171.	1652.	2881.	8104.	3226.	3.	0.	0.	0.	2623.
35	1964	0.	1887.	2844.	3601.	3456.	4307.	7573.	1490.	0.	0.	0.	0.	2082.
36	1965	0.	181.	605.	346.	760.	356.	2103.	764.	5.	0.	0.	0.	422.
37	1966	1.	104.	308.	314.	1270.	3082.	1946.	2502.	199.	0.	0.	10.	810.
38	1967	317.	1922.	1504.	1080.	984.	283.	11057.	7523.	1981.	431.	24.	0.	2253.
39	1968	47.	296.	2916.	1429.	1754.	8001.	5141.	3870.	4801.	1669.	0.	0.	2499.
40	1969	0.	849.	4864.	1909.	2133.	2975.	17290.	6216.	546.	260.	1547.	125.	3219.
41	1970	0.	4918.	6162.	4579.	10398.	2427.	11238.	4847.	296.	0.	0.	0.	3680.
42	1971	219.	482.	1719.	1202.	1891.	2284.	9947.	7886.	226.	0.	0.	0.	2151.
43	1972	22.	0.	1616.	1849.	2407.	5836.	10557.	9610.	3807.	1976.	126.	0.	3152.
44	1973	163.	3769.	6571.	6980.	8920.	8816.	10355.	7910.	2648.	6971.	704.	3.	5300.
45	1974	35.	660.	10709.	6780.	5500.	4214.	7821.	6277.	1042.	34.	0.	163.	3600.
46	1975	307.	1171.	4253.	3806.	3649.	5130.	7774.	2566.	1261.	503.	6.	1046.	2612.
47	1976	4869.	6263.	5032.	4220.	8664.	7541.	7560.	5196.	241.	37.	4135.	954.	4534.
48	1977	3673.	629.	891.	320.	496.	9904.	9424.	2477.	81.	1.	0.	290.	2361.
49	1978	5767.	3285.	6531.	10481.	6733.	2419.	9801.	5696.	2008.	0.	0.	0.	4381.
50	1979	0.	0.	268.	4931.	2763.	12084.	7780.	6548.	2163.	4.	36.	100.	3065.
	AVER	762.	1709.	3134.	3080.	3205.	4430.	8686.	4829.	1564.	458.	267.	523.	2712.

Table 8.11-4

MERRIMACK TRANSFER POTENTIAL, DAYS PUMP / MONTH BASED ON TREATMENT PLANT CAPACITY OF 200. MGD

QMERT=		3500.	3500.	2000.	2000.	2000.	6000.	6000.	4000.	4000.	3500.	3500.	3500.	CFS
IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	1.	5.	16.	30.	24.	29.	28.	30.	23.	0.	3.	0.	16.
2	1931	0.	9.	24.	11.	11.	14.	30.	31.	30.	10.	2.	2.	15.
3	1932	1.	7.	27.	31.	28.	19.	30.	26.	2.	3.	0.	8.	15.
4	1933	19.	30.	31.	31.	28.	31.	30.	30.	11.	0.	4.	13.	22.
5	1934	26.	22.	30.	31.	28.	27.	30.	30.	15.	1.	0.	14.	21.
6	1935	24.	30.	31.	31.	28.	31.	30.	30.	30.	24.	0.	11.	25.
7	1936	1.	12.	28.	30.	28.	21.	30.	28.	7.	0.	0.	0.	15.
8	1937	12.	14.	30.	31.	28.	24.	30.	31.	30.	15.	4.	0.	21.
9	1938	10.	25.	31.	31.	28.	30.	30.	31.	25.	30.	31.	25.	27.
10	1939	31.	30.	31.	31.	28.	31.	30.	31.	21.	4.	0.	0.	22.
11	1940	1.	11.	23.	20.	16.	2.	30.	31.	28.	24.	2.	8.	16.
12	1941	0.	22.	31.	31.	28.	9.	26.	16.	1.	8.	0.	0.	14.
13	1942	0.	6.	18.	27.	23.	28.	30.	28.	17.	16.	4.	1.	17.
14	1943	4.	27.	31.	31.	28.	31.	30.	31.	27.	4.	23.	5.	23.
15	1944	12.	29.	28.	25.	26.	17.	30.	30.	15.	20.	0.	10.	20.
16	1945	13.	16.	31.	31.	28.	31.	30.	31.	30.	30.	14.	5.	24.
17	1946	25.	22.	31.	31.	28.	30.	29.	31.	24.	5.	21.	6.	24.
18	1947	25.	23.	31.	30.	28.	29.	30.	31.	30.	18.	2.	2.	23.
19	1948	0.	15.	25.	21.	23.	15.	30.	31.	30.	25.	4.	0.	18.
20	1949	0.	14.	27.	31.	28.	28.	30.	28.	5.	0.	0.	3.	16.
21	1950	0.	6.	27.	31.	28.	17.	30.	28.	14.	0.	0.	0.	15.
22	1951	1.	12.	31.	31.	28.	31.	30.	31.	25.	23.	27.	22.	24.
23	1952	27.	30.	31.	31.	28.	31.	30.	31.	23.	1.	7.	0.	23.
24	1953	1.	4.	30.	31.	28.	31.	30.	31.	8.	0.	3.	0.	16.
25	1954	3.	11.	31.	31.	28.	31.	30.	31.	28.	11.	8.	30.	23.
26	1955	31.	30.	31.	31.	28.	31.	30.	29.	29.	1.	17.	12.	25.
27	1956	24.	30.	31.	28.	28.	30.	30.	31.	19.	14.	0.	8.	23.
28	1957	7.	12.	31.	31.	28.	31.	29.	21.	2.	2.	0.	0.	16.
29	1958	0.	19.	31.	31.	28.	31.	30.	31.	14.	4.	2.	0.	18.
30	1959	6.	19.	30.	28.	28.	27.	30.	26.	13.	12.	0.	6.	19.
31	1960	15.	30.	31.	31.	28.	29.	30.	31.	26.	0.	3.	19.	23.
32	1961	20.	30.	31.	31.	28.	31.	30.	31.	25.	3.	0.	9.	22.
33	1962	0.	13.	31.	31.	28.	18.	30.	31.	14.	0.	0.	0.	16.
34	1963	26.	30.	31.	31.	28.	22.	30.	31.	3.	0.	0.	0.	19.
35	1964	0.	23.	31.	31.	28.	28.	30.	26.	0.	0.	0.	0.	16.
36	1965	0.	4.	19.	16.	20.	11.	19.	22.	2.	0.	0.	0.	9.
37	1966	3.	7.	22.	23.	25.	30.	30.	31.	12.	0.	0.	3.	16.
38	1967	9.	26.	31.	31.	28.	10.	30.	31.	30.	27.	6.	0.	22.
39	1968	6.	13.	31.	31.	28.	14.	30.	31.	30.	23.	0.	0.	20.
40	1969	0.	20.	31.	31.	28.	23.	30.	31.	23.	2.	19.	5.	20.
41	1970	0.	27.	31.	31.	28.	31.	30.	31.	12.	0.	0.	0.	18.
42	1971	6.	18.	31.	31.	28.	31.	30.	31.	11.	0.	1.	0.	18.
43	1972	2.	0.	31.	31.	28.	30.	30.	31.	30.	31.	7.	0.	21.
44	1973	10.	30.	31.	31.	28.	31.	30.	31.	30.	27.	15.	1.	25.
45	1974	1.	17.	31.	31.	28.	31.	30.	31.	21.	7.	0.	11.	20.
46	1975	14.	25.	31.	31.	28.	31.	30.	27.	17.	14.	2.	7.	21.
47	1976	29.	30.	31.	31.	28.	31.	30.	31.	10.	2.	28.	23.	25.
48	1977	29.	18.	31.	30.	28.	31.	30.	27.	11.	1.	0.	9.	20.
49	1978	31.	30.	31.	31.	28.	20.	30.	31.	27.	0.	0.	0.	22.
50	1979	0.	0.	27.	30.	28.	31.	30.	31.	16.	1.	5.	11.	18.
	AVER	10.	19.	29.	29.	27.	26.	30.	29.	19.	9.	5.	6.	20.

Table 8.11-5
PERCENT REDUCTION OF HISTORIC FLOW, MERRIMACK RIVER AT LOWELL, DUE TO MDC PUMPING USING A 200 MGD PLANT

IY	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.56	2.29	6.06	6.73	5.45	2.49	2.56	4.95	4.02	0.0	1.31	0.0	3.34
2	1931	0.0	3.13	8.87	5.32	5.22	1.61	1.75	3.30	2.79	2.40	0.71	0.65	2.61
3	1932	0.47	1.99	5.61	3.43	4.69	2.59	1.39	3.63	0.46	1.25	0.0	2.38	2.52
4	1933	3.04	2.61	5.45	4.71	4.81	2.51	0.88	2.70	2.64	0.0	1.74	3.37	2.45
5	1934	5.12	5.41	6.89	5.56	7.91	2.48	1.08	2.89	3.05	0.53	0.0	3.52	3.00
6	1935	5.68	5.30	4.86	2.86	4.26	2.24	2.04	3.46	3.11	4.60	0.0	3.46	3.28
7	1936	0.10	3.50	6.40	4.65	6.72	0.46	1.49	3.53	1.40	0.0	0.0	0.0	1.75
8	1937	3.35	3.91	2.79	2.60	2.91	2.81	1.81	1.54	3.64	3.61	1.21	0.0	2.43
9	1938	2.70	2.56	2.60	3.30	2.83	2.70	2.36	3.95	4.35	3.32	3.97	1.16	2.73
10	1939	3.92	4.73	2.05	4.17	5.08	2.89	1.17	2.54	3.99	1.77	0.0	0.0	2.60
11	1940	0.55	3.18	6.92	7.52	6.18	0.34	1.09	1.64	2.73	5.70	0.89	2.58	2.26
12	1941	0.0	3.79	6.14	5.10	3.89	1.26	2.56	3.74	0.38	2.88	0.0	0.0	3.15
13	1942	0.0	2.32	5.89	7.83	8.71	1.92	2.06	4.31	2.29	3.99	1.16	0.40	3.00
14	1943	1.27	5.08	4.33	5.74	5.30	2.39	2.24	1.71	4.38	1.38	4.65	1.98	3.12
15	1944	3.33	3.26	6.35	9.25	9.00	2.28	1.64	3.00	1.40	4.03	0.0	2.53	3.05
16	1945	3.48	4.55	4.80	4.53	5.29	1.50	2.08	1.64	2.70	4.69	3.73	1.87	2.79
17	1946	5.07	3.67	3.07	3.50	4.32	1.54	2.88	2.61	2.82	1.42	4.72	1.74	2.90
18	1947	4.23	5.51	7.58	6.07	3.59	2.30	1.80	2.28	3.06	3.54	0.52	0.89	3.08
19	1948	0.0	3.78	9.03	8.55	7.11	0.95	2.25	2.13	2.98	5.40	0.31	0.0	2.82
20	1949	0.0	3.21	8.38	3.24	4.14	2.80	2.67	3.96	1.75	0.0	0.0	1.30	3.13
21	1950	0.0	1.94	7.48	5.03	5.57	1.98	1.68	3.77	2.78	0.0	0.0	0.0	2.87
22	1951	0.50	1.95	3.03	4.41	2.24	2.21	1.17	3.46	4.28	4.89	5.62	4.97	2.74
23	1952	4.48	1.97	3.01	2.30	2.46	2.48	1.12	2.22	2.15	0.24	2.59	0.0	2.10
24	1953	0.46	1.93	3.92	3.77	2.28	1.23	1.14	1.82	2.39	0.0	1.12	0.0	1.79
25	1954	1.67	2.74	3.44	6.59	3.95	2.69	1.88	1.25	3.02	3.02	2.42	2.14	2.50
26	1955	4.88	2.56	2.15	3.61	4.15	2.65	1.78	3.30	4.37	0.38	3.25	3.57	2.92
27	1956	3.07	2.27	6.17	2.18	4.22	3.71	1.20	1.78	2.48	3.29	0.0	2.75	2.42
28	1957	1.74	2.52	5.04	4.43	5.31	3.26	3.14	4.19	0.13	1.03	0.0	0.0	3.40
29	1958	0.0	4.20	2.64	2.76	3.09	2.52	1.18	2.01	3.29	1.63	0.68	0.0	2.16
30	1959	1.67	4.45	6.78	6.46	6.89	2.69	1.41	4.10	3.56	2.78	0.0	2.36	3.19
31	1960	1.93	2.75	2.27	3.52	3.10	3.85	0.93	2.24	3.67	0.0	1.19	3.36	2.24
32	1961	3.44	4.56	5.55	8.53	6.43	2.58	1.43	2.51	4.50	0.61	0.0	3.06	3.16
33	1962	0.0	3.05	8.40	6.13	8.86	2.17	1.34	3.18	3.54	0.0	0.0	0.0	2.85
34	1963	2.73	2.91	3.00	5.46	6.36	2.09	1.64	3.33	0.66	0.0	0.0	0.0	2.73
35	1964	0.0	3.79	4.61	3.93	4.04	2.16	1.72	3.97	0.0	0.0	0.0	0.0	2.76
36	1965	0.0	2.24	5.55	5.69	6.42	1.66	2.23	4.13	0.57	0.0	0.0	0.0	2.88
37	1966	1.22	2.19	8.28	8.56	6.61	2.65	3.32	3.78	3.02	0.0	0.0	1.53	3.61
38	1967	2.72	3.98	6.67	7.77	8.07	1.71	1.32	1.94	4.20	5.89	1.78	0.0	3.12
39	1968	1.48	3.40	4.54	6.85	6.16	0.80	2.17	3.01	2.64	3.48	0.0	0.0	2.74
40	1969	0.0	4.54	3.15	5.88	5.52	1.78	0.94	2.22	4.32	0.80	3.28	1.89	2.39
41	1970	0.0	2.44	2.61	3.29	1.68	3.07	1.31	2.62	3.21	0.0	0.0	0.0	2.10
42	1971	1.94	4.03	6.23	7.42	5.91	3.14	1.43	1.87	3.05	0.0	0.40	0.0	2.78
43	1972	0.93	0.0	6.43	5.98	5.13	1.95	1.37	1.61	3.03	4.51	1.99	0.0	2.54
44	1973	2.49	3.21	2.48	2.36	1.92	1.55	1.39	1.87	3.68	1.81	3.33	0.48	2.08
45	1974	0.39	3.77	1.64	2.42	2.86	2.41	1.68	2.21	3.53	2.14	0.0	3.34	2.22
46	1975	3.32	4.69	3.48	3.77	3.89	2.17	1.69	3.31	3.03	3.23	1.03	1.64	2.84
47	1976	2.57	2.29	3.07	3.50	1.97	1.72	1.72	2.51	3.02	0.39	2.76	4.83	2.40
48	1977	3.03	4.00	8.15	10.19	9.43	1.43	1.48	3.35	2.68	0.51	0.0	3.35	2.87
49	1978	2.43	3.48	2.49	1.67	2.43	1.96	1.44	2.36	3.76	0.0	0.0	0.0	2.16
50	1979	0.0	0.0	9.39	3.02	4.70	1.24	1.69	2.14	2.44	0.45	1.67	2.60	2.17
	AVER	2.56	3.19	4.01	4.13	4.08	1.97	1.54	2.49	2.98	2.52	1.88	1.84	2.62

The volume transferred after the above tests are made is called the actual transfer, AT(9).

A series of initial trial runs were made to obtain indications of the increase in safe yield as result of operating a hypothetical Merrimack alternative.

For these runs, the transfers were allowed during all months of the year, and the cutoff with respect to the combined storage in Quabbin and Wachusett was set at 98 percent. The safe yield reliability was set at 98.5 percent (8 monthly failures in 50 years).

MTPCAP MGD	System SY MGD	AT(9) MGD	AT(9) % of PT(9)	Change in SY % of MTPCAP
100	354	54.6	84.8	54.0
200	411	110.5	86.8	55.5
300	462	166.8	88.3	54.0

These data indicate that for the range of treatment plant capacities that were examined, the increase in the system safe yield varies directly as the plant capacity, and amounts to about 54 percent of the plant capacity.

In the above table, MTPCAP is the Merrimack Treatment Plant Capacity, AT(9) is the actual transfer and PT(9) is the potential transfer from the plant.

The system response as the trial yield is increase is as follows for the 200 MGD treatment plant:

Trial Yield MGD	No. Monthly Failures	AT(9) MGD	AT(9), % of PT(9)	QO(11) MGD	System Yield, MGD
400	6	105.9	83.2	57.2	398.4
405	7	107.9	84.7	55.0	402.9
410	8	110.1	86.5	53.3	407.6
411 (S.Y.)	8	110.5	86.8	52.6	408.5
412	9	110.8	87.0	52.0	409.3
413	9	111.0	87.2	51.8	410.0
414	11	111.2	87.3	51.2	410.9
415	11	111.6	87.6	50.9	411.7
420	13	113.8	89.4	49.1	415.7
425	15	115.4	90.6	47.1	419.7

The parameter QO(11) is the outflow from Quabbin Reservoir. A decrease in this value is, in effect, a contribution to the system demand.

After a review of the initial results, it was decided to adopt a treatment plant having an ultimate capacity of 235 MGD (see Section 8.12, Facility Design). The plant would

initially have a capacity of 165 MGD; this would later be increased to 200 MGD, and finally to 235 MGD. It was also decided that the plant would not be operated during the months of July through October when potential transfer volumes are low.

The HYDA and MDC003 models were rerun using the adopted sizes and rules. The results are:

MPTCAP MGD	System SY MGD	AT(9) MGD	PT(9) MGD	AT(9)/PT(9) Percent
165	386.0	81.4	92.6	87.9
200	404.0	99.6	111.9	89.0
235	421.5	117.8	131.1	89.9

Selected system parameters for the 235 MGD plant size are as follows:

Table 8.11-6 Potential Transfer, MGD

Table 8.11-7 Actual Transfer, MGD

Table 8.11-8 Potential No. Days/Month Plant Operates

Table 8.11-9 Actual No. Days/Month Plant Operates

Table 8.11-10 Summary Output for Trial

Effect on Streamflows and Reservoir Levels

The safe yield model contains a special subroutine, STREMA (not misspelled; the acronym was selected with the thought that variants would be called STREMB, STREMC, etc.), which can be activated to calculate mean monthly streamflows. The location of the streamflows is normally at a USGS gaging station, but any location can be used provided the drainage area is known.

The logic of STREMA can be explained with the aid of Figure 8.11-1, Sketch of Drainage Affecting Merrimack River at Lowell Flows. The flow of the Merrimack River at Lowell gage equals the runoff from its upstream local drainage area (shown as hatched) plus the outflows from the drainage areas defined by gages on the Nashua River at Pepperell, the Merrimack River at Manchester, and the Concord River at Lowell. The area of the local drainage area equals the total drainage area of the Merrimack at Lowell minus the total drainage area at the three upstream gages.

The HYDA program was used to calculate the historic local runoff for the Merrimack River at Lowell gage. Each monthly value was transformed to runoff per square mile by

Table 8.11-6 POTENTIAL TRANS 09 - MERRIMACK TO MDC SYSTEM, MGD

RUN KK-23 07/24/84 MERRIMACK 235 MGD TREATMENT PLANT IOA= 1 7 9 0 2 2 NTS= 1 NTTS= 2 TYIELD= 422. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	39.17	94.70	220.46	201.43	219.84	204.53	224.84	157.37	0.0	0.0	0.0	112.95
2	1931	0.0	70.50	157.70	72.11	82.23	94.51	235.00	235.00	227.30	0.0	0.0	0.0	97.60
3	1932	0.0	39.37	198.69	235.00	235.00	136.87	235.00	184.78	8.26	0.0	0.0	0.0	105.41
4	1933	0.0	235.00	235.00	235.00	235.00	228.80	235.00	227.42	78.47	0.0	0.0	0.0	141.77
5	1934	0.0	167.44	219.76	235.00	228.37	204.68	235.00	227.42	91.75	0.0	0.0	0.0	133.46
6	1935	0.0	227.95	234.51	235.00	235.00	235.00	235.00	225.05	235.00	0.0	0.0	0.0	154.34
7	1936	0.0	83.13	205.09	227.42	235.00	159.19	235.00	206.27	30.32	0.0	0.0	0.0	114.44
8	1937	0.0	104.05	225.68	235.00	235.00	181.93	235.00	235.00	235.00	0.0	0.0	0.0	139.75
9	1938	0.0	183.10	235.00	235.00	235.00	225.47	235.00	228.67	169.30	0.0	0.0	0.0	144.80
10	1939	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	116.67	0.0	0.0	0.0	146.08
11	1940	0.0	84.58	165.66	129.20	111.33	10.29	235.00	235.00	216.45	0.0	0.0	0.0	98.47
12	1941	0.0	172.33	233.88	235.00	235.00	55.36	196.40	114.89	6.03	0.0	0.0	0.0	103.11
13	1942	0.0	40.60	110.28	201.32	184.56	208.43	235.00	210.72	119.15	0.0	0.0	0.0	108.67
14	1943	0.0	209.27	227.84	230.68	235.00	223.65	235.00	235.00	205.60	0.0	0.0	0.0	149.34
15	1944	0.0	224.07	212.26	189.52	210.58	128.87	235.00	227.34	103.05	0.0	0.0	0.0	126.73
16	1945	0.0	119.58	235.00	235.00	235.00	235.00	234.92	235.00	235.00	0.0	0.0	0.0	146.32
17	1946	0.0	168.16	235.00	235.00	235.00	223.59	214.87	235.00	182.54	0.0	0.0	0.0	143.38
18	1947	0.0	165.56	228.25	227.42	235.00	219.84	235.00	235.00	235.00	0.0	0.0	0.0	147.60
19	1948	0.0	110.45	183.39	148.83	189.64	113.71	235.00	235.00	235.00	0.0	0.0	0.0	120.09
20	1949	0.0	103.77	182.81	235.00	235.00	212.26	235.00	209.68	39.17	0.0	0.0	0.0	120.41
21	1950	0.0	40.60	202.52	235.00	235.00	128.38	235.00	208.64	102.26	0.0	0.0	0.0	114.87
22	1951	0.0	89.18	235.00	235.00	235.00	235.00	235.00	235.00	185.98	0.0	0.0	0.0	139.79
23	1952	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	173.63	0.0	0.0	0.0	150.76
24	1953	0.0	31.33	218.65	229.50	235.00	235.00	235.00	235.00	60.22	0.0	0.0	0.0	122.85
25	1954	0.0	76.46	235.00	235.00	235.00	235.00	235.00	235.00	219.33	0.0	0.0	0.0	141.49
26	1955	0.0	235.00	235.00	235.00	235.00	235.00	235.00	197.36	217.89	0.0	0.0	0.0	151.21
27	1956	0.0	235.00	225.39	212.26	235.00	223.80	228.24	235.00	142.72	0.0	0.0	0.0	143.97
28	1957	0.0	68.91	235.00	235.00	235.00	235.00	223.43	151.33	1.94	0.0	0.0	0.0	114.94
29	1958	0.0	140.41	235.00	235.00	235.00	235.00	235.00	235.00	106.14	0.0	0.0	0.0	137.44
30	1959	0.0	130.64	227.42	207.03	235.00	197.44	235.00	191.18	101.83	0.0	0.0	0.0	126.35
31	1960	0.0	235.00	235.00	235.00	235.00	218.51	235.00	235.00	186.55	0.0	0.0	0.0	150.43
32	1961	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	178.21	0.0	0.0	0.0	151.14
33	1962	0.0	83.72	235.00	235.00	229.15	136.45	235.00	235.00	95.00	0.0	0.0	0.0	123.05
34	1963	0.0	235.00	235.00	235.00	235.00	163.15	235.00	235.00	12.14	0.0	0.0	0.0	131.39
35	1964	0.0	180.17	235.00	235.00	235.00	210.10	235.00	193.27	0.0	0.0	0.0	0.0	126.33
36	1965	0.0	31.33	115.63	107.72	158.92	73.02	148.83	154.66	9.56	0.0	0.0	0.0	66.09
37	1966	0.0	43.48	157.17	167.53	209.82	221.51	235.00	235.00	85.23	0.0	0.0	0.0	112.34
38	1967	0.0	201.86	235.00	234.72	235.00	69.69	235.00	235.00	235.00	0.0	0.0	0.0	139.02
39	1968	0.0	97.15	235.00	235.00	235.00	106.13	235.00	235.00	235.00	0.0	0.0	0.0	133.53
40	1969	0.0	156.67	235.00	235.00	235.00	143.26	235.00	235.00	157.16	0.0	0.0	0.0	135.18
41	1970	0.0	208.19	235.00	235.00	235.00	235.00	235.00	235.00	94.00	0.0	0.0	0.0	142.02
42	1971	0.0	127.76	235.00	235.00	235.00	235.00	235.00	235.00	78.61	0.0	0.0	0.0	134.14
43	1972	0.0	0.0	235.00	235.00	235.00	227.42	235.00	235.00	235.00	0.0	0.0	0.0	135.85
44	1973	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	235.00	0.0	0.0	0.0	155.81
45	1974	0.0	125.18	235.00	235.00	235.00	235.00	235.00	235.00	147.74	0.0	0.0	0.0	139.61
46	1975	0.0	193.60	235.00	235.00	235.00	235.00	235.00	203.56	129.86	0.0	0.0	0.0	141.09
47	1976	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	78.33	0.0	0.0	0.0	142.93
48	1977	0.0	134.17	225.39	212.73	215.89	235.00	235.00	204.68	72.42	0.0	0.0	0.0	127.41
49	1978	0.0	235.00	235.00	235.00	235.00	144.24	235.00	235.00	208.41	0.0	0.0	0.0	145.91
50	1979	0.0	0.0	182.96	227.42	235.00	235.00	235.00	235.00	125.33	0.0	0.0	0.0	122.42
	AVER	0.0	141.18	215.61	220.02	223.74	191.51	231.12	221.53	136.74	0.0	0.0	0.0	131.08

Table 8.11-7 ACTUAL TRANSFER 09 - MERRIMACK TO MDC SYSTEM, MGD

RUN KK-23 07/24/84 MERRIMACK 235 MGD TREATMENT PLANT IOA= 1 6 9 0 2 2 NTS= 1 NTTS= 2 TYIELD= 422. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	39.17	94.70	220.46	201.43	219.84	204.53	224.84	157.37	0.0	0.0	0.0	112.95
2	1931	0.0	70.50	157.70	72.11	82.23	94.51	235.00	235.00	227.30	0.0	0.0	0.0	97.60
3	1932	0.0	39.37	198.69	235.00	235.00	136.87	235.00	184.78	8.26	0.0	0.0	0.0	105.41
4	1933	0.0	235.00	235.00	235.00	235.00	228.80	235.00	227.42	78.47	0.0	0.0	0.0	141.77
5	1934	0.0	167.44	219.76	235.00	228.37	204.68	235.00	227.42	91.75	0.0	0.0	0.0	133.46
6	1935	0.0	227.95	234.51	235.00	235.00	235.00	235.00	225.05	235.00	0.0	0.0	0.0	154.34
7	1936	0.0	83.13	205.09	227.42	235.00	159.19	235.00	206.27	30.32	0.0	0.0	0.0	114.44
8	1937	0.0	104.05	225.68	235.00	235.00	181.93	235.00	235.00	0.0	0.0	0.0	0.0	120.43
9	1938	0.0	183.10	235.00	235.00	235.00	0.0	0.0	228.67	0.0	0.0	0.0	0.0	92.42
10	1939	0.0	0.0	0.0	235.00	0.0	0.0	0.0	0.0	116.67	0.0	0.0	0.0	29.55
11	1940	0.0	84.58	165.66	129.20	111.33	10.29	235.00	235.00	216.45	0.0	0.0	0.0	98.47
12	1941	0.0	172.33	233.88	235.00	235.00	55.36	196.40	114.89	6.03	0.0	0.0	0.0	103.11
13	1942	0.0	40.60	110.28	201.32	184.56	208.43	235.00	210.72	119.15	0.0	0.0	0.0	108.67
14	1943	0.0	209.27	227.84	230.68	235.00	223.65	235.00	235.00	205.60	0.0	0.0	0.0	149.34
15	1944	0.0	224.07	212.26	189.52	210.58	128.87	235.00	227.34	103.05	0.0	0.0	0.0	126.73
16	1945	0.0	119.58	235.00	235.00	235.00	235.00	234.92	235.00	235.00	0.0	0.0	0.0	146.32
17	1946	0.0	168.16	235.00	235.00	235.00	223.59	214.87	235.00	182.54	0.0	0.0	0.0	143.38
18	1947	0.0	165.56	228.25	227.42	235.00	219.84	235.00	235.00	235.00	0.0	0.0	0.0	147.60
19	1948	0.0	110.45	183.39	148.83	189.64	113.71	235.00	235.00	235.00	0.0	0.0	0.0	120.09
20	1949	0.0	103.77	182.81	235.00	235.00	212.26	235.00	209.68	39.17	0.0	0.0	0.0	120.41
21	1950	0.0	40.60	202.52	235.00	235.00	128.38	235.00	208.64	102.26	0.0	0.0	0.0	114.87
22	1951	0.0	89.18	235.00	235.00	235.00	235.00	235.00	235.00	185.98	0.0	0.0	0.0	139.79
23	1952	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	173.63	0.0	0.0	0.0	150.76
24	1953	0.0	31.33	218.65	229.50	235.00	235.00	235.00	0.0	0.0	0.0	0.0	0.0	97.94
25	1954	0.0	76.46	235.00	235.00	235.00	235.00	235.00	235.00	219.33	0.0	0.0	0.0	141.49
26	1955	0.0	235.00	235.00	235.00	0.0	0.0	235.00	0.0	217.89	0.0	0.0	0.0	96.46
27	1956	0.0	235.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.32
28	1957	0.0	68.91	235.00	235.00	235.00	235.00	223.43	151.33	1.94	0.0	0.0	0.0	114.94
29	1958	0.0	140.41	235.00	235.00	235.00	235.00	235.00	235.00	106.14	0.0	0.0	0.0	137.44
30	1959	0.0	130.64	227.42	207.03	235.00	197.44	235.00	191.18	101.83	0.0	0.0	0.0	126.35
31	1960	0.0	235.00	235.00	235.00	235.00	218.51	0.0	0.0	0.0	0.0	0.0	0.0	95.82
32	1961	0.0	235.00	235.00	235.00	235.00	235.00	235.00	0.0	0.0	0.0	0.0	0.0	116.53
33	1962	0.0	83.72	235.00	235.00	229.15	136.45	235.00	235.00	95.00	0.0	0.0	0.0	123.05
34	1963	0.0	235.00	235.00	235.00	235.00	163.15	235.00	235.00	12.14	0.0	0.0	0.0	131.39
35	1964	0.0	180.17	235.00	235.00	235.00	210.10	235.00	193.27	0.0	0.0	0.0	0.0	126.33
36	1965	0.0	31.33	115.63	107.72	158.92	73.02	148.83	154.66	9.56	0.0	0.0	0.0	66.09
37	1966	0.0	43.48	157.17	167.53	209.82	221.51	235.00	235.00	85.23	0.0	0.0	0.0	112.34
38	1967	0.0	201.86	235.00	234.72	235.00	69.69	235.00	235.00	235.00	0.0	0.0	0.0	139.02
39	1968	0.0	97.15	235.00	235.00	235.00	106.13	235.00	235.00	235.00	0.0	0.0	0.0	133.53
40	1969	0.0	156.67	235.00	235.00	235.00	143.26	235.00	235.00	157.16	0.0	0.0	0.0	135.18
41	1970	0.0	208.19	235.00	235.00	235.00	235.00	235.00	235.00	94.00	0.0	0.0	0.0	142.02
42	1971	0.0	127.76	235.00	235.00	235.00	235.00	235.00	235.00	78.61	0.0	0.0	0.0	134.14
43	1972	0.0	0.0	235.00	235.00	235.00	227.42	235.00	235.00	235.00	0.0	0.0	0.0	135.85
44	1973	0.0	235.00	235.00	235.00	235.00	235.00	235.00	235.00	235.00	0.0	0.0	0.0	155.81
45	1974	0.0	125.18	235.00	235.00	235.00	235.00	235.00	235.00	147.74	0.0	0.0	0.0	139.61
46	1975	0.0	193.60	235.00	235.00	235.00	235.00	235.00	203.56	129.86	0.0	0.0	0.0	141.09
47	1976	0.0	235.00	235.00	235.00	0.0	0.0	0.0	0.0	78.33	0.0	0.0	0.0	65.67
48	1977	0.0	134.17	225.39	212.73	215.89	235.00	235.00	204.68	72.42	0.0	0.0	0.0	127.41
49	1978	0.0	235.00	235.00	235.00	235.00	144.24	0.0	0.0	0.0	0.0	0.0	0.0	89.51
50	1979	0.0	0.0	182.96	227.42	235.00	235.00	0.0	0.0	0.0	0.0	0.0	0.0	72.84
	AVER	0.0	136.48	206.40	215.77	204.94	168.42	198.36	179.99	110.62	0.0	0.0	0.0	117.78

Table 8.11-8 SP - POTENTIAL NO DAYS/MON THAT MERRIMACK OPERATES

RUN KK-23 07/24/84 MERRIMACK 235 MGD TREATMENT PLANT IOA= 11692 2 0 1 NTS= 1 NTTS= 2 TYIELD= 422. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1	1930	0	5	16	30	24	29	28	30	23	0	0	0	185
2	1931	0	9	24	11	11	14	30	31	30	0	0	0	160
3	1932	0	7	27	31	28	19	30	26	2	0	0	0	170
4	1933	0	30	31	31	28	31	30	30	11	0	0	0	222
5	1934	0	22	30	31	28	27	30	30	15	0	0	0	213
6	1935	0	30	31	31	28	31	30	30	30	0	0	0	241
7	1936	0	12	28	30	28	21	30	28	7	0	0	0	184
8	1937	0	14	30	31	28	24	30	31	30	0	0	0	218
9	1938	0	25	31	31	28	30	30	31	25	0	0	0	231
10	1939	0	30	31	31	28	31	30	31	21	0	0	0	233
11	1940	0	11	23	20	16	2	30	31	28	0	0	0	161
12	1941	0	22	31	31	28	9	26	16	1	0	0	0	164
13	1942	0	6	18	27	23	28	30	28	17	0	0	0	177
14	1943	0	27	31	31	28	31	30	31	27	0	0	0	236
15	1944	0	29	28	25	26	17	30	30	15	0	0	0	200
16	1945	0	16	31	31	28	31	30	31	30	0	0	0	228
17	1946	0	22	31	31	28	30	29	31	24	0	0	0	226
18	1947	0	23	31	30	28	29	30	31	30	0	0	0	232
19	1948	0	15	25	21	23	15	30	31	30	0	0	0	190
20	1949	0	14	27	31	28	28	30	28	5	0	0	0	191
21	1950	0	6	27	31	28	17	30	28	14	0	0	0	181
22	1951	0	12	31	31	28	31	30	31	25	0	0	0	219
23	1952	0	30	31	31	28	31	30	31	23	0	0	0	235
24	1953	0	4	30	31	28	31	30	31	8	0	0	0	193
25	1954	0	11	31	31	28	31	30	31	28	0	0	0	221
26	1955	0	30	31	31	28	31	30	29	29	0	0	0	239
27	1956	0	30	31	28	28	30	30	31	19	0	0	0	227
28	1957	0	12	31	31	28	31	29	21	2	0	0	0	185
29	1958	0	19	31	31	28	31	30	31	14	0	0	0	215
30	1959	0	19	30	28	28	27	30	26	13	0	0	0	201
31	1960	0	30	31	31	28	29	30	31	26	0	0	0	236
32	1961	0	30	31	31	28	31	30	31	25	0	0	0	237
33	1962	0	13	31	31	28	18	30	31	14	0	0	0	196
34	1963	0	30	31	31	28	22	30	31	3	0	0	0	206
35	1964	0	23	31	31	28	28	30	26	0	0	0	0	197
36	1965	0	4	19	16	20	11	19	22	2	0	0	0	113
37	1966	0	7	22	23	25	30	30	31	12	0	0	0	180
38	1967	0	26	31	31	28	10	30	31	30	0	0	0	217
39	1968	0	13	31	31	28	14	30	31	30	0	0	0	208
40	1969	0	20	31	31	28	23	30	31	23	0	0	0	217
41	1970	0	27	31	31	28	31	30	31	12	0	0	0	221
42	1971	0	18	31	31	28	31	30	31	11	0	0	0	211
43	1972	0	0	31	31	28	30	30	31	30	0	0	0	211
44	1973	0	30	31	31	28	31	30	31	30	0	0	0	242
45	1974	0	17	31	31	28	31	30	31	21	0	0	0	220
46	1975	0	25	31	31	28	31	30	27	17	0	0	0	220
47	1976	0	30	31	31	28	31	30	31	10	0	0	0	222
48	1977	0	18	31	30	28	31	30	27	11	0	0	0	206
49	1978	0	30	31	31	28	20	30	31	27	0	0	0	228
50	1979	0	0	27	30	28	31	30	31	16	0	0	0	193
	TOT	0	933	1454	1465	1344	1282	1481	1474	926	0	0	0	10359

Table 8.11-9 SP - ACTUAL NO DAYS/MON THAT MERRIMACK OPERATES

RUN KK-23 07/24/84 MERRIMACK 235 MGD TREATMENT PLANT IOA= 11693 2 0 1 NTS= 1 NTTS= 2 TYIELD= 422. MGD

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOT
1	1930	0	5	16	30	24	29	28	30	23	0	0	0	185
2	1931	0	9	24	11	11	14	30	31	30	0	0	0	160
3	1932	0	7	27	31	28	19	30	26	2	0	0	0	170
4	1933	0	30	31	31	28	31	30	30	11	0	0	0	222
5	1934	0	22	30	31	28	27	30	30	15	0	0	0	213
6	1935	0	30	31	31	28	31	30	30	30	0	0	0	241
7	1936	0	12	28	30	28	21	30	28	7	0	0	0	184
8	1937	0	14	30	31	28	24	30	31	0	0	0	0	188
9	1938	0	25	31	31	28	0	0	31	0	0	0	0	146
10	1939	0	0	0	31	0	0	0	0	21	0	0	0	52
11	1940	0	11	23	20	16	2	30	31	28	0	0	0	161
12	1941	0	22	31	31	28	9	26	16	1	0	0	0	164
13	1942	0	6	18	27	23	28	30	28	17	0	0	0	177
14	1943	0	27	31	31	28	31	30	31	27	0	0	0	236
15	1944	0	29	28	25	26	17	30	30	15	0	0	0	200
16	1945	0	16	31	31	28	31	30	31	30	0	0	0	228
17	1946	0	22	31	31	28	30	29	31	24	0	0	0	226
18	1947	0	23	31	30	28	29	30	31	30	0	0	0	232
19	1948	0	15	25	21	23	15	30	31	30	0	0	0	190
20	1949	0	14	27	31	28	28	30	28	5	0	0	0	191
21	1950	0	6	27	31	28	17	30	28	14	0	0	0	181
22	1951	0	12	31	31	28	31	30	31	25	0	0	0	219
23	1952	0	30	31	31	28	31	30	31	23	0	0	0	235
24	1953	0	4	30	31	28	31	30	0	0	0	0	0	154
25	1954	0	11	31	31	28	31	30	31	28	0	0	0	221
26	1955	0	30	31	31	0	0	30	0	29	0	0	0	151
27	1956	0	30	0	0	0	0	0	0	0	0	0	0	30
28	1957	0	12	31	31	28	31	29	21	2	0	0	0	185
29	1958	0	19	31	31	28	31	30	31	14	0	0	0	215
30	1959	0	19	30	28	28	27	30	26	13	0	0	0	201
31	1960	0	30	31	31	28	29	0	0	0	0	0	0	149
32	1961	0	30	31	31	28	31	30	0	0	0	0	0	181
33	1962	0	13	31	31	28	18	30	31	14	0	0	0	196
34	1963	0	30	31	31	28	22	30	31	3	0	0	0	206
35	1964	0	23	31	31	28	28	30	26	0	0	0	0	197
36	1965	0	4	19	16	20	11	19	22	2	0	0	0	113
37	1966	0	7	22	23	25	30	30	31	12	0	0	0	180
38	1967	0	26	31	31	28	10	30	31	30	0	0	0	217
39	1968	0	13	31	31	28	14	30	31	30	0	0	0	208
40	1969	0	20	31	31	28	23	30	31	23	0	0	0	217
41	1970	0	27	31	31	28	31	30	31	12	0	0	0	221
42	1971	0	18	31	31	28	31	30	31	11	0	0	0	211
43	1972	0	0	31	31	28	30	30	31	30	0	0	0	211
44	1973	0	30	31	31	28	31	30	31	30	0	0	0	242
45	1974	0	17	31	31	28	31	30	31	21	0	0	0	220
46	1975	0	25	31	31	28	31	30	27	17	0	0	0	220
47	1976	0	30	31	31	0	0	0	0	10	0	0	0	102
48	1977	0	18	31	30	28	31	30	27	11	0	0	0	206
49	1978	0	30	31	31	28	20	0	0	0	0	0	0	140
50	1979	0	0	27	30	28	31	0	0	0	0	0	0	116
	TOT	0	903	1392	1437	1232	1129	1271	1197	750	0	0	0	9311

Table 8.11-10 SUMMARY OUTPUT FOR TRIAL NO. 1

RUN KK-23 07/24/84 MERRIMACK 235 MGD TREATMENT PLANT NMFAIL = 9 1 2 9 NTTS= 2 TYIELD= 422. MGD

IALT =	0	0	0	0	1	0	0	2	0	0		
SPT =	804429.	4820.	7168528.	5067666.	0.	0.	36500.	0.	2392195.	0.	0.	0.
SAT =	800656.	8593.	3226078.	5014718.	0.	0.	36500.	0.	2149481.	0.	0.	0.
PCT =	99.5	178.3	45.0	99.0	0.0	0.0	100.0	0.0	89.9	0.0	0.0	0.0

INITIAL/FINAL RESERVOIR STORAGES - MG

NTT	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM
1	412240./373692.	64968./ 58471.	7254./ 7254.	2000./ 2000.
2	373692./373692.	58471./ 58471.	7254./ 7254.	2000./ 2000.

WATER BALANCE - MGD

1	WATERSHED INFLOW	165.34	119.04	20.23	53.10
2	PRECIP ON RESERVOIRS	71.47	13.64	4.31	1.62
3	EVAPORATION LOSS	-44.05	-8.19	-2.64	-0.99
4	SEEPAGE LOSS	0.0	-0.94	0.0	0.0
5	OUTFLOW TO STREAM	-46.30	-11.14	-23.90	-77.63
6	CONDUIT TRANSFER IN	43.87	177.24	2.00	23.90
7	CONDUIT TRANSFER OUT	-176.77	-276.78	0.0	0.0
8	DIRECT WITHDRAWAL	-13.56	-12.89	0.0	0.0
9	NEGATIVE STOR ADJUST	0.0	0.0	0.0	0.0
10	DECREASE IN STORAGE	0.0	0.0	0.0	0.0
	SUM OF ABOVE	-0.00	-0.00	-0.00	0.00
11	RESERVOIR YIELD-MGD	192.76	123.56	21.90	53.73
	RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01

INTERBASIN TRANSFERS - MGD

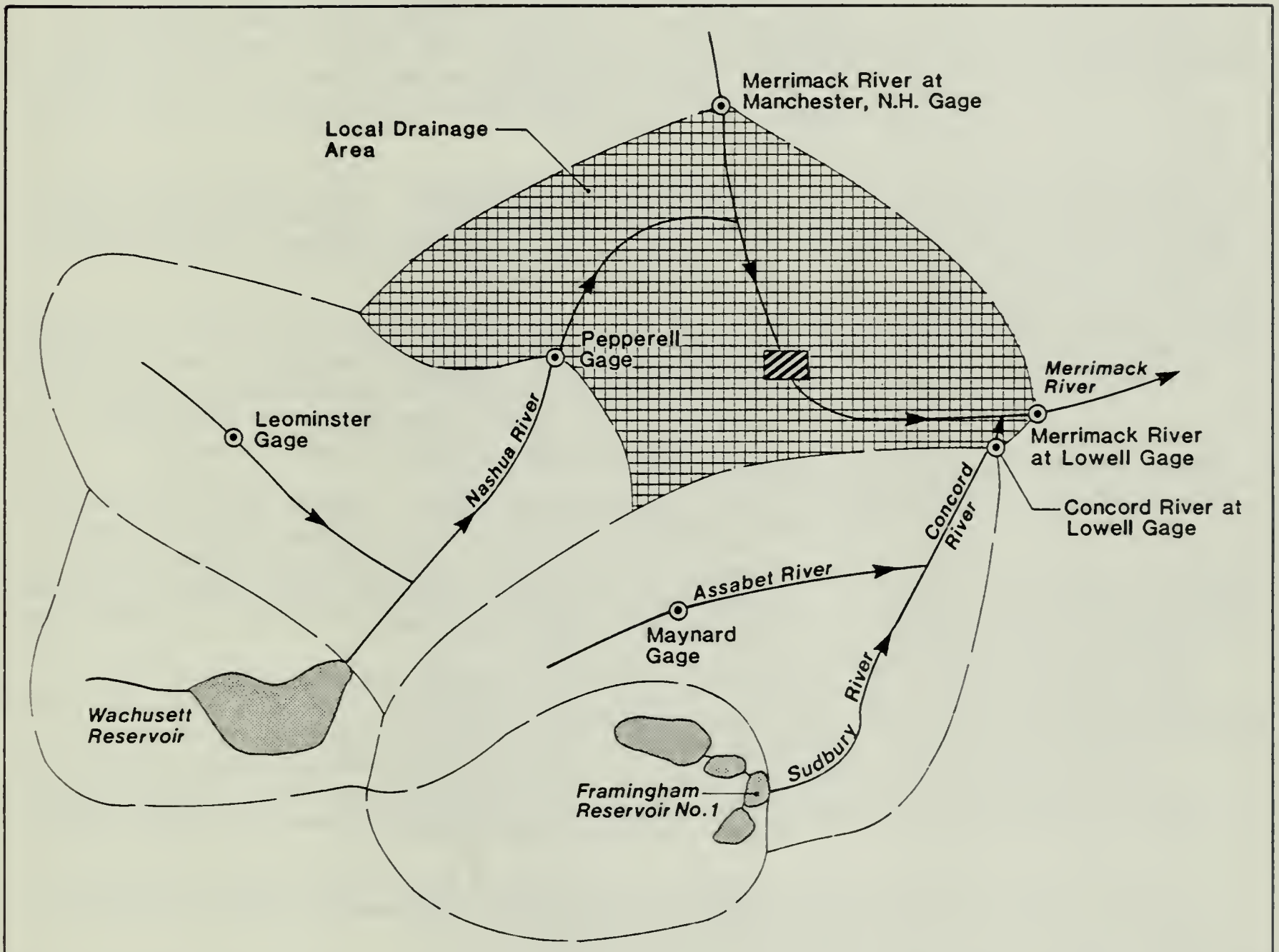
CONNECTICUT TO NASHUA	177.24
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	85.33
WEST TO SUDBURY & BOSTON	262.57
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	380.35
WEST	38.65
TOTAL	419.01

NO. OF TYPE 0 ERRORS = 0 NO. OF TYPE 1 ERRORS = 0

dividing the local drainage area. The resulting data file was then used as input to the simulation model. This technique generally eliminates the effects of reservoir and lake regulation in upstream areas (e.g., Wachusett Reservoir), producing what can be called natural runoff for the local area.



Legend

- Proposed Water Treatment Plant
- Drainage Area
- Direction of Flow

Figure 8.11-1.
Drainage Affecting Merrimack River Flows at Lowell

Not to Scale

The local runoff at the Pepperell gage could be determined in a similar manner if the basic USGS data tape used as input contained the daily discharges from Wachusett Reservoir, but it does not. While monthly values are available, it was decided to avoid the time consuming process of entering the values manually to establish a data file. Instead, the USGS gage on the North Nashua River at Leominster was used as the basis for local runoff per square mile in the area above the Pepperell gage and below Wachusett Reservoir. A similar condition applies to the Concord River -- its local runoff per square mile was assumed to be that of the USGS gage on the Assabet River at Maynard. These data also become input to the simulation model. The safe yield program determines the mean monthly streamflows as follows:

- Nashua River at Pepperell. Sum of the local runoff per square mile times the local drainage area, plus the outflow from Wachusett Reservoir (as calculated monthly by the model).

- Concord River at Lowell. Sum of the local runoff per square mile times the local drainage area, plus the outflow from Framingham Reservoir No. 1 (calculated monthly by the model, whether or not any of the Sudbury/Framingham supply options are active).

- Merrimack River at Lowell. Sum of the outflows of Nashua River at Pepperell and the Concord River at Lowell (as obtained above), plus the flow of the Merrimack River at Manchester (HYDA input), plus the runoff per square mile times the local drainage area.

The program can also estimate the streamflow of the Merrimack River at the Pawtucket Dam in Lowell (the flow at the Merrimack/Lowell gage minus the flow at the Concord/Lowell gage value), and the Merrimack River at Lawrence (the flow at the Merrimack/Lowell gage value plus its local runoff per square mile times 80 square miles).

The change in streamflows that could result from the operation of the Merrimack alternative must be viewed in more than one context.

- Compared to historic streamflows--but recognizing that historic flows were influenced by historic MDC demands, which were only 171 MGD in 1942, the year that Quabbin began operating. Also, Sudbury Reservoir has had an intermittent history of operation during the historic period of hydrologic record of 1930 to 1979.

- Compared to "today's" streamflows--these are generated by the simulation model using a trial yield of 300 MGD, the safe yield of the existing system.

- Compared to future streamflows without the Merrimack alternative--this presumes the no-action alternative under which demand increases but not the supply. Streamflows would be expected to decrease as reservoir spillages decreased.

- Compared to future streamflows with the Merrimack alternative--for this, the safe yield model generates streamflows using the system safe yield with the alternative.

The safe yield model was used to calculate streamflows under several scenarios. The results are summarized in Table 8.11-11. Run LL-06 was made to obtain the historic flows in the Nashua River at Pepperell, the Concord River at Lowell, and the Merrimack River at Lowell. It also calculated the flows at these three stations using a trial yield (demand) of 300 MGD. The outflows from Quabbin, Wachusett, and Framingham No. 1 Reservoirs were also determined.

Runs LL-08, LL-10, and LL-11 were made with the Merrimack alternative active, using treatment plant capacities of 165, 200, and 235 MGD, respectively.

The above runs were all made without the so-called "existing Sudbury" supply source. It involves a 40-MGD treatment plant operated periodically 8½ months per year based on available runoff, and with it the existing system would have a safe yield of 317 MGD. Run LL-07 was made with Sudbury (using subroutine SUDBRY) but without any Merrimack alternative. Run LL-09 was the same plus a 165-MGD Merrimack treatment plant. These two runs were made primarily to obtain additional data to compare to the historic flows.

The results show a better comparison of historic and simulated flows (without the Merrimack alternative) when Sudbury is active than when it is not. This may be due to historic flows being subject to withdrawals from Sudbury that are transferred to Boston and hence do not contribute to the Merrimack at Lowell flows.

The runs without Sudbury indicate that operation of the Merrimack alternative would cause the flows in the Nashua River to increase slightly, up to about 2 percent (mean value for 50 years of simulation). The flows in the Merrimack at Lowell would decrease, up to a mean of 2 percent. The outflows from Quabbin would also decrease,

TABLE 8.11-11

SIMULATION OF FLOWS IN MERRIMACK RIVER AT LOWELL
MEAN DAILY VALUES FOR 50 YEARS

Run	SUDBRY?	Merrimack TPC (MGD)	Safe Yield (MGD)	Actual Yield (MGD)	Nashua River at Pepperell, MA Q (MGD)	Nashua River at Pepperell, MA Δ[b] (MGD)	Concord River at Lowell Q (MGD)	Concord River at Lowell Δ[b] (MGD)	Merrimack River at Lowell Q (MGD)	Merrimack River at Lowell Δ[b] (MGD)	Outflow Quabbin (MGD)	Outflow Wachusett (MGD)	Outflow Framingham (MGD)	AT9[a] (MGD)
LL-06	(historic flow)				372.22		401.36		4856.42					
LL-06	No	0	300	298.35	368.85	0.00	414.97	0.00	4866.66	0.00	55.35	4.91	77.63	0.00
LL-08	No	165	386	383.51	371.27	2.42	414.97	0.00	4787.71	-78.95	49.14	7.34	77.63	81.37
LL-10	No	200	404	401.36	372.87	4.02	414.97	0.00	4771.07	-95.59	47.97	8.93	77.63	99.62
LL-11	No	235	422	419.01	375.07	6.22	414.97	0.00	4755.11	-111.55	46.30	11.14	77.63	117.78
LL-07	Yes	0	317	315.01	369.15	0.00	400.68	0.00	4852.66	0.00	52.73	5.21	63.34	0.00
LL-09	Yes	165	403[c]	400.06	373.93	4.78	399.96	-0.72	4773.98	-78.68	46.41	10.00	62.62	82.75

[a] AT(9) is actual transfer, Merrimack Treatment Plant to MDC System.

[b] Delta values are simulated for Merrimack alternative trial yield minus simulated for existing system.

[c] Not safe yield--caused 11 rather than 8 monthly failures.

from a mean of 55.35 MGD (system yield of 300 MGD, no Merrimack) to 46.30 MGD (system yield of 422 MGD, 235 MGD Merrimack plant). This reduction in Quabbin spillage would be offset by an increase in Wachusett spillage. It is likely that if the Merrimack alternative were to be constructed, the Quabbin/Wachusett operating rules would be modified slightly to avoid increasing the spillage from Wachusett.

When the HYDA model was used to estimate the potential transfers, it used the historic daily flows to calculate excess volumes. The question arises as to whether the historic flows, so used, are a fair representation of future flows. It would appear so since the values of the flows of the Merrimack River at Lowell are greater for a simulated trial yield of 300 MGD than the historic flows (4,867 MGD versus 4,856 MGD). A possible explanation for this is that as the Quabbin and Ware River watersheds (Connecticut River Basin) began supplying water to Boston, the demand on the Wachusett Reservoir and Sudbury watersheds (Merrimack River Basin) were less affected by the increasing demands, and hence the Merrimack flows were not greatly influenced.

Merrimack Flows at Pawtucket Dam, Lowell

The flow lost for hydropower use at Pawtucket Dam is equal to the MDC withdrawals unless the flows after withdrawal exceed the hydropower capacity, in which case there would be no loss to hydropower even with MDC withdrawals. In order to estimate the power loss under this hypothesis, it would be necessary to have the simulation model generate daily flow values, which it does not do. However, an approximate estimate was made using the HYDA model to calculate the potential power loss and modifying the results using the simulation model output.

The historic daily flows for the Merrimack River at Lowell were first reduced by excluding the Concord River flows, using ratio of drainage areas:

$$\frac{4635-405}{4635} = 0.91262$$

Thus the Pawtucket flows become 0.91262 times the Merrimack flows at the Lowell gage.

This reduction was applied to the historic daily flows to approximate the daily Pawtucket Dam flows. If the HYDA model indicated that there was a potential transfer on a day, the potential transfer was subtracted from the Pawtucket flows and the power loss was set equal to the potential transfer, unless the resulting Pawtucket flows

exceeded 12,000 cfs, in which case the power loss was set equal to zero. The results, by months, are shown in Table 8.11-12 for a treatment plant capacity of 235 MGD.

The actual transfers, AT(9), are less than the potential transfers because there are times when Quabbin and Wachusett Reservoirs are more than 98 percent full, and it was decided that the treatment plant would not operate from July through October. The actual transfers are also shown in Table 8.11-12.

Assuming that the relationship between potential and actual transfers also applies to the power loss, the actual power loss can be found as a direct ratio. It is also shown on Table 8.11-12, and equals 88 MGD as a mean annual value.

Table 8.11-12 shows that in April the power loss is only 29 percent of the MDC withdrawals because the flows often exceed the design capacity of the hydropower facilities.

The choice of 12,000 cfs as the hydropower capacity was based on a quick scan of the installed and/or proposed capacity data, and may or may not be the best estimate for future conditions. However, the results of the analysis may be useful because they suggest that the mitigation cost for power loss is probably considerably less than the withdrawals alone would indicate.

TABLE 8.11-12: MERRIMACK TRANSFERS AND PAWTUCKET DAM POWER LOSS, 235 MGD TREATMENT PLANT

	PT(9)	AT(9)	Pawtucket Dam Potential	Pawtucket Dam Actual
Oct	72	0	66	0
Nov	141	136	123	119
Dec	216	206	190	181
Jan	220	216	198	194
Feb	224	205	202	185
Mar	192	168	117	102
Apr	231	198	66	57
May	222	180	146	118
Jun	137	111	122	99
Jul	61	0	58	0
Aug	37	0	35	0
Sep	42	0	37	0
Mean	149	118	113	88

PT = Potential Transfers, MGD
AT = Actual Transfers, MGD

Hydrologic Impacts

The safe yield model was used to evaluate system-wide hydrologic impacts for the Merrimack alternative. The run number, HY-14 dated 06/21/85, applies to operations with a 235-MGD treatment plant active. Two trials were made, the first with the alternative inactive using a trial yield of 300 MGD (safe yield) to establish baseline data, and the second with the alternative active using a trial yield of 422 MGD (safe yield for a 235-MGD plant). Summary data for the first trial are shown in Table 8.11-13 and in Table 8.11-14 for the second trial. The mean values for key parameters are shown in Table 8.11-15.

General comments on the hydrologic impacts follow.

(1) The Merrimack alternative is the only one that can independently provide sufficient water to meet the projected demand in the year 2020. For this reason, its impact on safe yield is considered to be high.

(2) The alternative has some effect on Quabbin and Wachusett Reservoirs. Under baseline conditions, these reservoirs supply 300 MGD on a year-round basis. With the Merrimack alternative active at full capacity (235 MGD treatment plant), the system demand is 422 MGD. From about December to May, 235 MGD are generally supplied from Merrimack and 187 MGD from Quabbin and Wachusett. But during the summer and fall, the reservoirs must supply the entire 422 MGD. This semi-annual change in the demand for reservoir water is not a significant factor for Quabbin because of its large storage volume, but it causes a decrease in the efficiency of Wachusett Reservoir (its mean spillage increasing form 4.9 to 11.1 MGD). This situation could be corrected by changing the operating rules for Wachusett such that it would be drawn down more in later fall and winter in order to provide more storage for the spring runoff.

Comments on selected parameter tables follow.

Table 8.11-16 Quabbin Reservoir End-of-Month Storage, Percent of Net Storage (differences, chronological). The storage is generally less with Merrimack active (trial yield 422 MGD) than for baseline conditions (trial yield 300 MGD). In 1965 and 1966, the Merrimack flows were low and Quabbin was drawn down to its minimum pool sooner than for the baseline case, but for the next several years it was slightly higher due to the availability of the Merrimack supply.

Table 8.11-13: SUMMARY OUTPUT FOR TRIAL NO. 1

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) NMFAIL = 8 0 0 8 NTTS= 2 TYIELD= 300. MGD

TOTAL TRANSFERS MGD	SHAFT 8 TO QUABBIN	SHAFT 8 TO WACH	QUABBIN TO WACH	WACH TO MARL TUN	NORTHF TO QUABBIN	MILLERS TO QUABBIN	WACH TO SUDBURY	SUDBURY TO BOSTON	MERRIMACK TO BOSTON	PLYMOUTH TO BOSTON	LOCALS TO SYSTEM	FRAM TO SUDBURY
POTENTIAL =	44.06	0.28	396.71	273.46	0.0	0.0	2.00	0.0	0.0	0.0	0.0	0.0
ACTUAL =	43.46	0.88	167.17	271.82	0.0	0.0	2.00	0.0	0.0	0.0	0.0	0.0
PCT =	98.64	313.75	42.14	99.40	0.0	0.0	100.00	0.0	0.0	0.0	0.0	0.0

	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM	FRAM#1	FRAM#2	FRAM#3
MEAN RESERVOIR ELEVATION - FT BCB	518.93	390.47	260.00	177.58	0.0	0.0	0.0
WATER BALANCE - MGD							
1 WATERSHED INFLOW	164.38	119.11	20.23	53.03			
2 PRECIP ON RESERVOIRS	73.40	13.56	4.31	1.77			
3 EVAPORATION LOSS	-45.12	-8.14	-2.64	-1.08			
4 SEEPAGE LOSS	0.0	-0.93	0.0	0.0			
5 OUTFLOW TO STREAM	-55.35	-4.91	-23.90	-77.61			
6 CONDUIT TRANSFER IN	43.46	168.05	2.00	23.90			
7 CONDUIT TRANSFER OUT	-167.17	-273.82	0.0	0.0			
8 DIRECT WITHDRAWAL	-13.60	-12.92	0.0	0.0			
11 RESERVOIR YIELD-MGD	192.66	123.60	21.90	53.72			
RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01			

INTERBASIN TRANSFERS - MGD

CONNECTICUT TO NASHUA	168.05
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	91.57
WEST TO SUDBURY & BOSTON	259.62
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	259.62
WEST	38.73
TOTAL	298.35

Table 8.11-14: SUMMARY OUTPUT FOR TRIAL NO. 2

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) NMFAIL = 9 1 2 9 NTTS= 2 TYIELD= 422. MGD

TOTAL TRANSFERS MGD	SHAFT 8 TO QUABBIN	SHAFT 8 TO WACH	QUABBIN TO WACH	WACH TO MARL TUN	NORTHF TO QUABBIN	MILLERS TO QUABBIN	WACH TO SUDBURY	SUDBURY TO BOSTON	MERRIMACK TO BOSTON	PLYMOUTH TO BOSTON	LOCALS TO SYSTEM	FRAM TO SUDBURY
POTENTIAL =	44.08	0.26	392.80	277.68	0.0	0.0	2.00	0.0	131.08	0.0	0.0	0.0
ACTUAL =	43.87	0.47	176.77	274.78	0.0	0.0	2.00	0.0	117.78	0.0	0.0	0.0
PCT =	99.53	178.29	45.00	98.96	0.0	0.0	100.00	0.0	89.85	0.0	0.0	0.0

	QUABBIN	WACHUSETT	SUDBURY	FRAMINGHAM	FRAM#1	FRAM#2	FRAM#3
MEAN RESERVOIR ELEVATION - FT BCB	516.51	391.07	260.00	177.58	0.0	0.0	0.0
WATER BALANCE - MGD							
1 WATERSHED INFLOW	165.34	119.04	20.23	53.03			
2 PRECIP ON RESERVOIRS	71.47	13.64	4.31	1.77			
3 EVAPORATION LOSS	-44.05	-8.19	-2.64	-1.08			
4 SEEPAGE LOSS	0.0	-0.94	0.0	0.0			
5 OUTFLOW TO STREAM	-46.30	-11.14	-23.90	-77.61			
6 CONDUIT TRANSFER IN	43.87	177.24	2.00	23.90			
7 CONDUIT TRANSFER OUT	-176.77	-276.78	0.0	0.0			
8 DIRECT WITHDRAWAL	-13.56	-12.89	0.0	0.0			
11 RESERVOIR YIELD-MGD	192.76	123.56	21.90	53.72			
RESERVOIR YIELD-MGD/SM	1.04	1.15	1.00	1.01			

INTERBASIN TRANSFERS - MGD

CONNECTICUT TO NASHUA	177.24
NASHUA TO SUDBURY RESERVOIR	2.00
NASHUA TO SUDBURY & BOSTON	85.33
WEST TO SUDBURY & BOSTON	262.57
SUDBURY TO BOSTON	0.0

SYSTEM ACTUAL YIELD - MGD

FRAM./BOSTON	380.35
WEST	38.65
TOTAL	419.01

Table 8.11-15: Summary of Hydrologic Impacts Merrimack Alternative, Run No. HY-14

(Units in MGD except as noted)
(Values are mean for 50 years)
(235 MGD Treatment Plant)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
SYSTEM YIELDS					
Trial Yield	300	422	122	41	--
Actual Yield	298	419	121	41	High
TRANSFERS (Actual)					
Northfield-Quabbin	--	--	--	--	--
Millers-Quabbin	--	--	--	--	--
Merrimack-MDC	--	118	118	--	--
Sudbury-MDC	--	--	--	--	--
Framingham-Sudbury	--	--	--	--	--
Quabbin-Wachusett	42	45	3	7	Low
RESERVOIRS					
Quabbin-Net Storage (%)	69	63	--	-6	Low
Quabbin-Elevation (Ft-BCB)	519	517	-2	-2	Low
Quabbin-Area (Sq. Mi.)	34.2	33.3	-0.9	-3	Low
Wachusett-Net Storage (%)	39	47	--	8	Low
Wachusett-Elevation (Ft-BCB)	390	391	1	1	Low
Wachusett-Area (Sq. Mi.)	--	--	--	--	--
Sudbury-Net Storage (%)	--	--	--	--	--
Sudbury-Elevation (Ft-BCB)	--	--	--	--	--
Sudbury-Area (Sq. Mi.)	--	--	--	--	--

Table 8.11-15 (Continued)

	Baseline	With Alternative	Difference	Percent Difference	Hydrologic Impact Significance
STREAMFLOW					
Millers River at Erving	--	--	--	--	--
Connecticut River at Montague	--	--	--	--	--
Swift River at Quabbin	55	46	-9	-16	Low
Chicopee River at Indian Orchard	504	495	-9	-2	Low
Connecticut River at Thompsonville	10532	10523	-9	0	Low
S. Nashua River at Wachusett	4.9	11.1	6.2	127	Low
Nashua River at E. Pepperell	369	375	6	2	Low
Sudbury River at Framingham	--	--	--	--	--
Concord River at Lowell	--	--	--	--	--
Merrimack River at Lowell	4867	4755	-112	-2	Low
OTHER OR SPECIAL					
Weeks Supply in Quabbin & Wachusett	86	56	-30	35	Low

Notes:

(1) Values in parentheses are not representative of the 600 values used to determine the mean value.
(2) Percentage change in Quabbin Elevation based on reservoir depth of 110 feet.
Percentage change in Wachusett Elevation based on reservoir depth of 95 feet.
Percentage change in Sudbury Elevation based on reservoir depth of 30 feet.
(3) Hyphen (-) indicates datum is not applicable or not meaningful.
(4) See text for reasons for impact significance.

Table 8.11-16: DELTA VALUES QUABBIN RESER. EOM STORAGE - PERCENT OF NET STORAGE

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 0 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	-11	-11	-12	-11	-10	-8	-7	-6	-6	-7	-9	-10	-9
2	1931	-12	-12	-12	-12	-13	-13	-13	-13	-11	-11	-12	-14	-12
3	1932	-15	-16	-15	-14	-12	-12	-12	-10	-11	-13	-15	-16	-14
4	1933	-18	-17	-15	-13	-12	-13	-12	-12	-11	-13	-15	-16	-14
5	1934	-18	-17	-16	-14	-13	-13	-13	-13	-11	-13	-15	-16	-15
6	1935	-18	-16	-15	-14	-12	-12	-12	-10	-8	-9	-10	-12	-12
7	1936	-13	-14	-13	-11	-10	-10	-7	-5	-5	-8	-10	-11	-10
8	1937	-13	-13	-13	-13	-12	-9	-4	-1	2	0	-2	-3	-7
9	1938	-5	-4	-3	-1	-1	-1	0	0	0	0	-1	0	-1
10	1939	0	0	0	-1	-1	0	0	-2	-4	-5	-7	-9	-2
11	1940	-10	-11	-10	-10	-10	-11	-11	-11	-10	-10	-13	-14	-11
12	1941	-16	-15	-14	-12	-11	-12	-11	-11	-12	-14	-15	-17	-13
13	1942	-18	-19	-19	-18	-18	-18	-18	-16	-14	-16	-18	-19	-18
14	1943	-21	-20	-18	-17	-16	-16	-16	-16	-13	-14	-15	-17	-16
15	1944	-18	-17	-16	-15	-14	-14	-14	-12	-11	-13	-15	-16	-14
16	1945	-17	-17	-16	-15	-13	-13	-13	-13	-12	-12	-13	-15	-14
17	1946	-16	-16	-14	-13	-11	-11	-11	-9	-7	-9	-10	-12	-12
18	1947	-13	-13	-11	-10	-9	-8	-8	-8	-5	-5	-7	-8	-9
19	1948	-10	-10	-9	-9	-8	-8	-8	-8	-8	-7	-9	-10	-8
20	1949	-12	-12	-11	-10	-9	-9	-8	-5	-6	-7	-9	-10	-9
21	1950	-12	-13	-12	-10	-9	-9	-9	-7	-7	-8	-10	-11	-10
22	1951	-13	-13	-12	-10	-10	-10	-10	-9	-6	-8	-9	-11	-10
23	1952	-12	-12	-12	-12	-12	-11	-11	-9	-5	-6	-8	-10	-10
24	1953	-11	-12	-11	-10	-10	-10	-3	0	-3	-4	-6	-8	-7
25	1954	-9	-10	-9	-7	-6	-5	-5	-4	0	-1	-3	-4	-5
26	1955	-6	-5	-3	1	0	0	0	0	0	-2	-2	-5	-2
27	1956	-3	0	-1	0	-1	0	0	0	-3	-3	-6	-8	-2
28	1957	-9	-10	-8	-7	-6	-6	-5	-3	-4	-6	-7	-9	-7
29	1958	-10	-10	-9	-8	-6	-6	-6	-6	-5	-6	-9	-11	-8
30	1959	-12	-12	-11	-10	-8	-8	-7	-4	-3	-5	-8	-9	-8
31	1960	-11	-10	-8	-5	-3	0	0	0	-3	-3	-6	-8	-5
32	1961	-9	-8	-6	-5	-4	-4	0	0	-2	-3	-5	-7	-4
33	1962	-8	-9	-7	-6	-5	-4	-4	-3	-2	-4	-5	-7	-5
34	1963	-8	-7	-6	-4	-3	-2	-2	0	-1	-2	-4	-6	-4
35	1964	-7	-6	-5	-3	-2	-2	-2	1	0	-2	-3	-5	-3
36	1965	-6	-7	-7	-8	-7	-8	-7	-7	-8	-10	-11	-13	-8
37	1966	-14	-15	-15	-13	-12	-12	-10	-9	-10	-8	-3	-1	-10
38	1967	0	0	0	0	0	0	0	0	1	1	0	-2	0
39	1968	-3	-3	-2	-1	1	1	1	2	3	3	1	0	0
40	1969	-2	-1	0	2	3	3	3	3	6	4	2	1	2
41	1970	0	0	2	3	3	4	4	5	7	5	3	2	3
42	1971	0	0	2	3	4	6	6	6	8	7	5	2	4
43	1972	0	0	1	2	4	4	4	4	4	3	1	0	2
44	1973	-2	-1	-1	0	0	0	0	0	2	2	1	-1	0
45	1974	-2	-2	-2	-2	-1	-1	-1	1	5	3	1	0	0
46	1975	-2	-1	0	1	3	3	3	5	7	5	3	2	3
47	1976	0	0	0	1	0	0	0	0	0	-3	-5	-7	-1
48	1977	-8	-8	-6	-5	-4	-4	-4	-4	-3	-5	-6	-8	-6
49	1978	-9	-8	-8	-6	-4	0	0	0	-1	-4	-7	-9	-5
50	1979	-10	-12	-11	-11	-10	-3	0	0	-3	-5	-7	-9	-7
	AVER	-9	-9	-8	-7	-6	-6	-5	-4	-4	-5	-7	-8	-7

Table 8.11-17 Wachusett Reservoir End-of-Month Storage, Percent of Net Storage (differences, sorted). Wachusett has a 50-year mean of plus 8 percent compared to Quabbin's minus 7 percent. The table provides an indication of how the operating rule for Quabbin/Wachusett storage should be modified if the Merrimack alternative is constructed, i.e., provide more storage space from December through May.

Table 8.11-18 Quabbin Reservoir End-of-Month Elevations (differences, sorted). (See Figure 8.11-2 for comparison to baseline.)

Table 8.11-19 Wachusett Reservoir End-of-Month Elevations (differences, sorted).

Table 8.11-20 Actual Transfer, Merrimack to MDC System (sorted). The zero values from November through June can be attributed to Quabbin and Wachusett being full rather than lack of potential transfer (see also Tables 8.11-6 and 8.11-7).

Figure 8.11-2.
Quabbin Reservoir Elevation

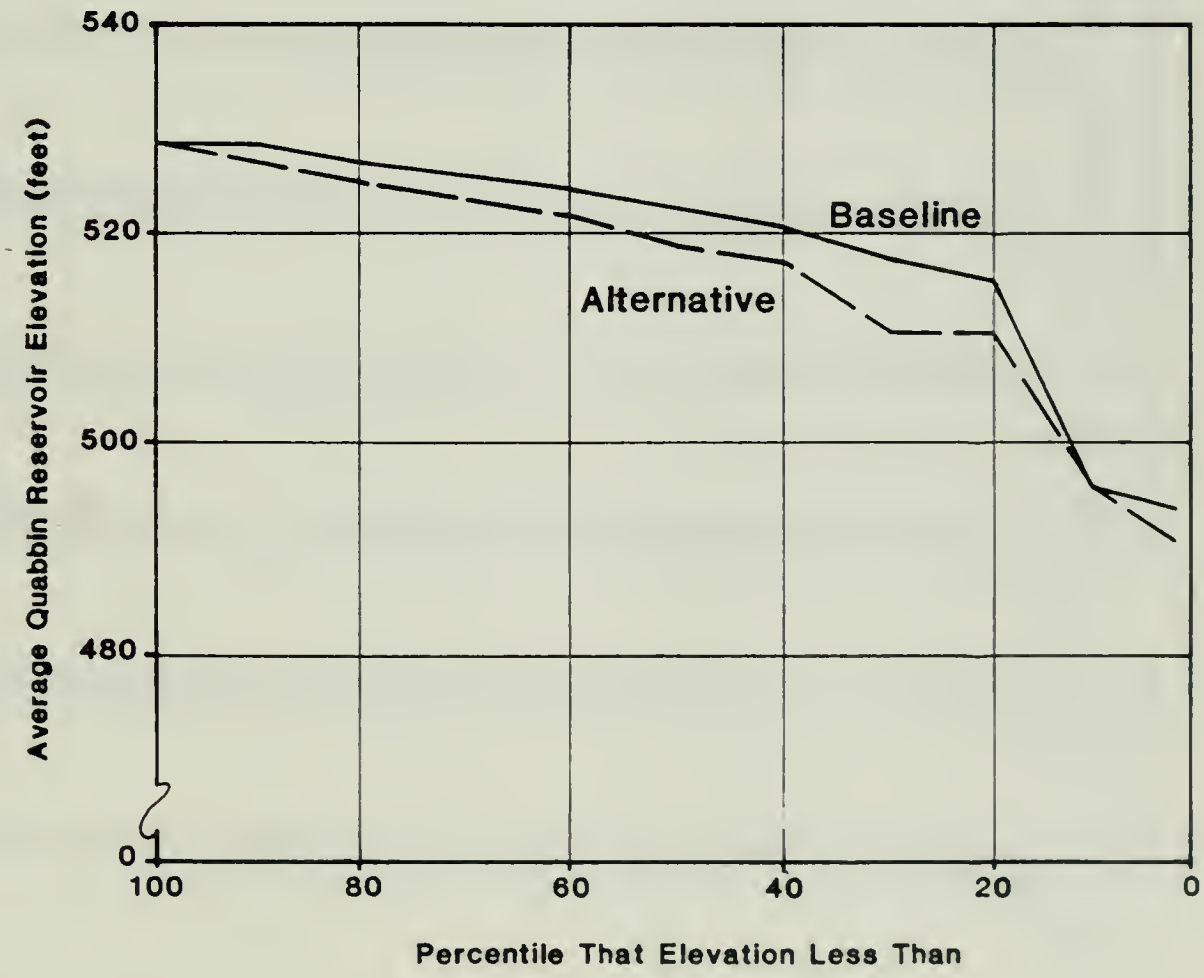


Table 8.11-17: DELTA VALUES WACHUSETT RESER. EOM STORAGE - PERCENT OF NET STORAGE

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	36	74	98	100	100	100	100	64	2	0	28	50
2	98.0	0	32	70	88	100	78	100	100	61	0	0	0	39
3	96.0	0	30	61	68	82	60	76	99	56	0	0	0	35
4	94.0	0	23	45	67	67	57	73	98	43	0	0	0	31
5	92.0	0	17	42	66	64	53	73	95	41	0	0	0	20
6	90.0	0	7	38	65	56	51	69	69	38	0	0	0	20
7	88.0	0	5	35	33	55	50	68	65	30	0	0	0	19
8	86.0	0	4	34	31	41	48	68	64	19	0	0	0	18
9	84.0	0	3	31	23	34	46	67	64	17	0	0	0	17
10	82.0	0	0	21	20	34	42	61	57	16	0	0	0	17
11	80.0	0	0	21	17	28	42	60	55	14	0	0	0	16
12	78.0	0	0	19	14	22	40	56	53	14	0	0	0	16
13	76.0	0	0	12	7	19	38	51	53	3	0	0	0	15
14	74.0	0	0	2	7	12	34	47	51	1	0	0	0	14
15	72.0	0	0	0	5	12	34	45	49	0	0	0	0	13
16	70.0	0	0	0	0	12	34	45	48	0	0	0	0	12
17	68.0	0	0	0	0	8	32	42	47	0	0	0	0	12
18	66.0	0	0	0	0	7	31	39	47	0	0	0	0	12
19	64.0	0	0	0	0	4	31	38	44	0	0	0	0	11
20	62.0	0	0	0	0	4	31	37	41	0	0	0	0	11
21	60.0	0	0	0	0	2	30	37	36	0	0	0	0	10
22	58.0	0	0	0	0	0	28	37	33	0	0	0	0	9
23	56.0	0	0	0	0	0	28	37	31	0	0	0	0	9
24	54.0	0	0	0	0	0	27	37	30	0	0	0	0	9
25	52.0	0	0	0	0	0	19	37	23	0	0	0	0	8
26	50.0	0	0	0	0	0	14	34	15	0	0	0	0	7
27	48.0	0	0	0	0	0	12	34	15	0	0	0	0	7
28	46.0	0	0	0	0	0	0	29	12	0	0	0	0	6
29	44.0	0	0	0	0	0	0	24	10	0	0	0	0	5
30	42.0	0	0	0	0	0	0	21	10	0	0	0	0	4
31	40.0	0	0	0	0	0	0	21	9	0	0	0	0	4
32	38.0	0	0	0	0	0	0	17	1	0	0	0	0	4
33	36.0	0	0	0	0	0	0	6	0	0	0	0	0	4
34	34.0	0	0	0	0	0	0	3	0	0	0	0	0	4
35	32.0	0	0	0	0	0	0	0	0	0	0	0	0	2
36	30.0	0	0	0	0	0	0	0	0	0	0	0	0	2
37	28.0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	26.0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	24.0	0	0	0	0	0	0	0	0	0	-10	0	0	0
40	22.0	0	0	0	0	0	0	0	-2	0	-11	0	0	-1
41	20.0	0	0	0	0	0	0	0	-14	0	-20	0	0	-1
42	18.0	0	0	0	0	0	0	0	-19	-1	-24	0	0	-2
43	16.0	0	0	0	0	0	-1	0	-22	-14	-33	0	0	-4
44	14.0	0	0	0	0	0	-3	0	-37	-26	-33	0	0	-4
45	12.0	0	0	0	0	0	-4	-8	-38	-30	-33	-3	0	-5
46	10.0	0	0	0	0	0	-6	-26	-38	-33	-33	-7	0	-5
47	8.0	0	0	0	0	-3	-28	-35	-47	-33	-33	-26	0	-9
48	6.0	-1	0	0	0	-26	-37	-37	-58	-33	-33	-30	0	-11
49	4.0	-5	-12	-3	-23	-32	-69	-38	-64	-33	-33	-33	-2	-25
50	2.0	-39	-37	-54	-33	-33	-70	-64	-73	-74	-33	-35	-9	-28
	AVER	-1	2	9	11	13	17	28	22	3	-7	-3	0	8

Table 8.11-18: DELTA VALUES QUABBIN RESER. END-OF-MONTH ELEV (BOSTON CITY BASE)

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	0	1	2	2	3	3	3	4	3	2	1	2
2	98.0	0	0	1	2	2	2	2	2	3	2	2	1	1
3	96.0	0	0	0	1	2	2	2	2	3	2	1	1	1
4	94.0	0	0	0	1	1	2	2	2	2	2	1	0	1
5	92.0	0	0	0	1	1	1	1	2	2	1	1	0	1
6	90.0	0	0	0	0	0	0	0	1	2	1	1	0	0
7	88.0	-1	0	0	0	0	0	0	0	1	1	0	0	0
8	86.0	-1	0	0	0	0	0	0	0	1	1	0	0	0
9	84.0	-1	0	0	0	0	0	0	0	1	1	0	0	0
10	82.0	-1	-1	0	0	0	0	0	0	1	0	0	0	0
11	80.0	-1	-1	-1	0	0	0	0	0	0	0	-1	-1	0
12	78.0	-2	-1	-1	0	0	0	0	0	0	0	-1	-1	-1
13	76.0	-2	-1	-1	0	0	0	0	0	0	-1	-1	-1	-1
14	74.0	-2	-2	-1	-1	-1	0	0	0	0	-1	-1	-2	-1
15	72.0	-2	-2	-2	-1	-1	0	0	0	0	-1	-1	-2	-1
16	70.0	-3	-2	-2	-1	-1	0	0	0	0	-1	-2	-2	-1
17	68.0	-3	-3	-2	-2	-1	-1	0	0	0	-1	-2	-2	-1
18	66.0	-3	-3	-2	-2	-1	-1	0	0	-1	-1	-2	-2	-2
19	64.0	-3	-3	-3	-2	-1	-1	-1	0	-1	-1	-2	-2	-2
20	62.0	-3	-3	-3	-2	-1	-1	-1	0	-1	-1	-2	-3	-2
21	60.0	-3	-3	-3	-2	-2	-1	-1	0	-1	-1	-2	-3	-2
22	58.0	-3	-3	-3	-2	-2	-1	-1	-1	-1	-1	-2	-3	-2
23	56.0	-3	-3	-3	-2	-2	-2	-1	-1	-1	-2	-2	-3	-2
24	54.0	-3	-3	-3	-3	-2	-2	-1	-1	-1	-2	-2	-3	-2
25	52.0	-4	-3	-3	-3	-3	-2	-2	-1	-1	-2	-2	-3	-2
26	50.0	-4	-4	-3	-3	-3	-3	-2	-1	-1	-2	-2	-3	-3
27	48.0	-4	-4	-4	-3	-3	-3	-2	-1	-1	-2	-2	-3	-3
28	46.0	-4	-4	-4	-3	-3	-3	-2	-2	-2	-2	-3	-3	-3
29	44.0	-4	-4	-4	-3	-3	-3	-2	-2	-2	-2	-3	-3	-3
30	42.0	-4	-4	-4	-3	-3	-3	-3	-2	-2	-2	-3	-3	-3
31	40.0	-4	-4	-4	-3	-3	-3	-3	-2	-2	-2	-3	-4	-3
32	38.0	-4	-4	-4	-4	-3	-3	-3	-2	-2	-3	-3	-4	-3
33	36.0	-4	-4	-4	-4	-3	-3	-3	-3	-2	-3	-3	-4	-3
34	34.0	-4	-4	-4	-4	-3	-3	-3	-3	-2	-3	-3	-4	-3
35	32.0	-5	-5	-4	-4	-3	-3	-3	-3	-2	-3	-3	-4	-4
36	30.0	-5	-5	-4	-4	-4	-4	-4	-3	-3	-3	-3	-4	-4
37	28.0	-5	-5	-4	-4	-4	-4	-4	-3	-3	-3	-4	-4	-4
38	26.0	-5	-5	-5	-4	-4	-4	-4	-3	-3	-3	-4	-4	-4
39	24.0	-5	-5	-5	-4	-4	-4	-4	-3	-3	-3	-4	-5	-4
40	22.0	-5	-5	-5	-5	-4	-4	-4	-4	-3	-4	-4	-5	-4
41	20.0	-6	-6	-5	-5	-4	-4	-4	-4	-4	-4	-5	-5	-5
42	18.0	-6	-6	-5	-5	-5	-5	-4	-4	-4	-4	-5	-6	-5
43	16.0	-6	-6	-6	-5	-5	-5	-5	-4	-4	-4	-5	-6	-5
44	14.0	-7	-7	-6	-6	-5	-5	-5	-4	-4	-5	-5	-6	-5
45	12.0	-7	-7	-6	-6	-5	-5	-5	-5	-4	-5	-5	-6	-5
46	10.0	-7	-7	-6	-6	-6	-5	-5	-5	-4	-5	-6	-6	-5
47	8.0	-7	-7	-7	-6	-6	-6	-5	-5	-4	-5	-6	-6	-6
48	6.0	-7	-8	-7	-7	-6	-6	-5	-5	-5	-5	-6	-7	-6
49	4.0	-7	-8	-8	-7	-6	-6	-6	-5	-5	-5	-6	-7	-6
50	2.0	-9	-8	-8	-8	-7	-7	-6	-6	-5	-6	-7	-8	-7
	AVER	-4	-3	-3	-3	-2	-2	-2	-2	-1	-2	-2	-3	-2

Table 8.11-19: DELTA VALUES WACHUSETT RESER. END-OF-MONTH ELEV (BOSTON CITY BASE)

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	3	6	7	8	8	8	8	5	0	0	2	4
2	98.0	0	2	5	7	8	6	8	8	4	0	0	0	3
3	96.0	0	2	5	5	6	4	6	8	4	0	0	0	3
4	94.0	0	2	3	5	5	4	5	7	3	0	0	0	2
5	92.0	0	1	3	5	5	4	5	7	3	0	0	0	2
6	90.0	0	1	3	5	4	4	5	5	3	0	0	0	1
7	88.0	0	0	3	3	4	4	5	5	2	0	0	0	1
8	86.0	0	0	2	2	3	4	5	5	1	0	0	0	1
9	84.0	0	0	2	2	3	4	5	5	1	0	0	0	1
10	82.0	0	0	2	2	3	3	5	4	1	0	0	0	1
11	80.0	0	0	2	1	2	3	4	4	1	0	0	0	1
12	78.0	0	0	1	1	2	3	4	4	1	0	0	0	1
13	76.0	0	0	1	1	1	3	4	4	0	0	0	0	1
14	74.0	0	0	0	1	1	3	4	4	0	0	0	0	1
15	72.0	0	0	0	0	1	3	3	4	0	0	0	0	1
16	70.0	0	0	0	0	1	3	3	4	0	0	0	0	1
17	68.0	0	0	0	0	1	2	3	3	0	0	0	0	1
18	66.0	0	0	0	0	1	2	3	3	0	0	0	0	1
19	64.0	0	0	0	0	0	2	3	3	0	0	0	0	1
20	62.0	0	0	0	0	0	2	3	3	0	0	0	0	1
21	60.0	0	0	0	0	0	2	3	3	0	0	0	0	1
22	58.0	0	0	0	0	0	2	3	2	0	0	0	0	1
23	56.0	0	0	0	0	0	2	3	2	0	0	0	0	1
24	54.0	0	0	0	0	0	2	3	2	0	0	0	0	1
25	52.0	0	0	0	0	0	1	3	2	0	0	0	0	1
26	50.0	0	0	0	0	0	1	3	1	0	0	0	0	1
27	48.0	0	0	0	0	0	1	2	1	0	0	0	0	1
28	46.0	0	0	0	0	0	0	2	1	0	0	0	0	1
29	44.0	0	0	0	0	0	0	2	1	0	0	0	0	0
30	42.0	0	0	0	0	0	0	2	1	0	0	0	0	0
31	40.0	0	0	0	0	0	0	2	1	0	0	0	0	0
32	38.0	0	0	0	0	0	0	1	0	0	0	0	0	0
33	36.0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	34.0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	32.0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	30.0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	28.0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	26.0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	24.0	0	0	0	0	0	0	0	0	0	-1	0	0	0
40	22.0	0	0	0	0	0	0	0	0	0	-1	0	0	0
41	20.0	0	0	0	0	0	0	0	-1	0	-1	0	0	0
42	18.0	0	0	0	0	0	0	0	-2	0	-2	0	0	0
43	16.0	0	0	0	0	0	0	0	-2	-1	-2	0	0	0
44	14.0	0	0	0	0	0	0	0	-3	-2	-2	0	0	0
45	12.0	0	0	0	0	0	0	-1	-3	-2	-2	0	0	0
46	10.0	0	0	0	0	0	0	-2	-3	-2	-2	-1	0	0
47	8.0	0	0	0	0	0	-2	-3	-3	-2	-2	-2	0	-1
48	6.0	0	0	0	0	-2	-3	-3	-4	-2	-2	-2	0	-1
49	4.0	0	-1	0	-2	-2	-5	-3	-5	-2	-2	-2	0	-2
50	2.0	-3	-3	-4	-2	-2	-5	-5	-5	-6	-3	-3	-1	-2
	AVER	0	0	1	1	1	1	2	2	0	0	0	0	1

Table 8.11-20: ACTUAL TRANSFER 09 - MERRIMACK TO MDC SYSTEM, MGD

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) C= 2 6 9 0 0-2 NTS= 2 NTTS= 2 TYIELD= 422. MGD

N	PCTILE	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	235	235	235	235	235	235	235	235	0	0	0	156
2	98.0	0	235	235	235	235	235	235	235	235	0	0	0	154
3	96.0	0	235	235	235	235	235	235	235	235	0	0	0	151
4	94.0	0	235	235	235	235	235	235	235	235	0	0	0	149
5	92.0	0	235	235	235	235	235	235	235	235	0	0	0	148
6	90.0	0	235	235	235	235	235	235	235	235	0	0	0	146
7	88.0	0	235	235	235	235	235	235	235	235	0	0	0	143
8	86.0	0	235	235	235	235	235	235	235	235	0	0	0	142
9	84.0	0	235	235	235	235	235	235	235	227	0	0	0	142
10	82.0	0	235	235	235	235	235	235	235	219	0	0	0	141
11	80.0	0	228	235	235	235	235	235	235	218	0	0	0	141
12	78.0	0	224	235	235	235	235	235	235	216	0	0	0	140
13	76.0	0	209	235	235	235	235	235	235	206	0	0	0	140
14	74.0	0	208	235	235	235	235	235	235	186	0	0	0	139
15	72.0	0	202	235	235	235	235	235	235	183	0	0	0	137
16	70.0	0	194	235	235	235	235	235	235	174	0	0	0	136
17	68.0	0	183	235	235	235	229	235	235	157	0	0	0	135
18	66.0	0	180	235	235	235	227	235	235	157	0	0	0	134
19	64.0	0	172	235	235	235	224	235	235	148	0	0	0	134
20	62.0	0	168	235	235	235	224	235	235	130	0	0	0	133
21	60.0	0	167	235	235	235	222	235	235	119	0	0	0	131
22	58.0	0	166	235	235	235	220	235	235	117	0	0	0	127
23	56.0	0	157	235	235	235	220	235	235	106	0	0	0	127
24	54.0	0	140	235	235	235	219	235	229	103	0	0	0	126
25	52.0	0	134	235	235	235	212	235	227	102	0	0	0	126
26	50.0	0	131	235	235	235	210	235	227	102	0	0	0	123
27	48.0	0	128	235	235	235	208	235	227	95	0	0	0	120
28	46.0	0	125	234	235	235	205	235	225	94	0	0	0	120
29	44.0	0	120	228	235	235	197	235	225	92	0	0	0	120
30	42.0	0	110	228	235	235	182	235	211	85	0	0	0	117
31	40.0	0	104	227	235	235	163	235	210	79	0	0	0	115
32	38.0	0	104	226	235	235	159	235	209	78	0	0	0	115
33	36.0	0	97	225	235	235	144	235	206	78	0	0	0	114
34	34.0	0	89	220	235	235	143	235	205	72	0	0	0	113
35	32.0	0	85	219	231	235	137	235	204	39	0	0	0	112
36	30.0	0	84	212	230	229	136	235	193	30	0	0	0	109
37	28.0	0	83	205	227	228	129	235	191	12	0	0	0	105
38	26.0	0	76	203	227	216	128	235	185	10	0	0	0	103
39	24.0	0	71	199	227	211	114	223	155	8	0	0	0	98
40	22.0	0	69	183	220	210	106	215	151	6	0	0	0	98
41	20.0	0	43	183	213	201	95	205	115	2	0	0	0	98
42	18.0	0	41	183	207	190	73	196	0	0	0	0	0	96
43	16.0	0	41	166	201	185	70	149	0	0	0	0	0	96
44	14.0	0	39	158	190	159	55	0	0	0	0	0	0	92
45	12.0	0	39	157	168	111	10	0	0	0	0	0	0	90
46	10.0	0	31	116	149	82	0	0	0	0	0	0	0	73
47	8.0	0	31	110	129	0	0	0	0	0	0	0	0	66
48	6.0	0	0	95	108	0	0	0	0	0	0	0	0	66
49	4.0	0	0	0	72	0	0	0	0	0	0	0	0	30
50	2.0	0	0	0	0	0	0	0	0	0	0	0	0	19
	AVER	0	136	206	216	205	168	198	180	111	0	0	0	118

Table 8.11-21 Outflow from Quabbin Reservoir, MGD (differences, chronological). The values reflect a reduction in spillage when the reservoir is full. The reductions also apply to all downstream flows.

Table 8.11-22 Streamflow--Chicopee River at Indian Orchard (percent differences, sorted).

Table 8.11-23 Streamflow--Connecticut River at Thompsonville (percent differences, chronological). It may seem incongruous that taking water from the Merrimack River would cause a reduction in the flow of the Connecticut River in Connecticut, but it is possible during a few months. (See Figure 8.11-3.)

Table 8.11-24 Outflow from Wachusett Reservoir, MGD (differences, chronological). Note the impact of a single event, the hurricane of 1938. Increases in the Wachusett outflow represent water lost to the supply system (although it might be recouped at the Merrimack Treatment Plant). The plus 6.2 MGD here partly offsets the minus 9.0 MGD change in the Quabbin outflows, and suggests that the operating rules need to be adjusted slightly to accommodate the Merrimack alternative.

Table 8.11-25 Streamflow--Merrimack River at Pawtucket Dam, Lowell (percent differences, sorted). (See Figure 8.11-4.)

Table 8.11-26 Streamflow--Merrimack River at USGS Station, Lowell (percent differences, sorted). This location is downstream of the Concord River confluence.

Table 8.11-27 Streamflow--Merrimack River at Lawrence Dam, Lawrence (percent differences, sorted). This location has 80 square miles of additional drainage area located below the USGS Station in Lowell.

Figure 8.11-3.
Connecticut River Streamflow at Thompsonville (Mass./Conn. State Line)

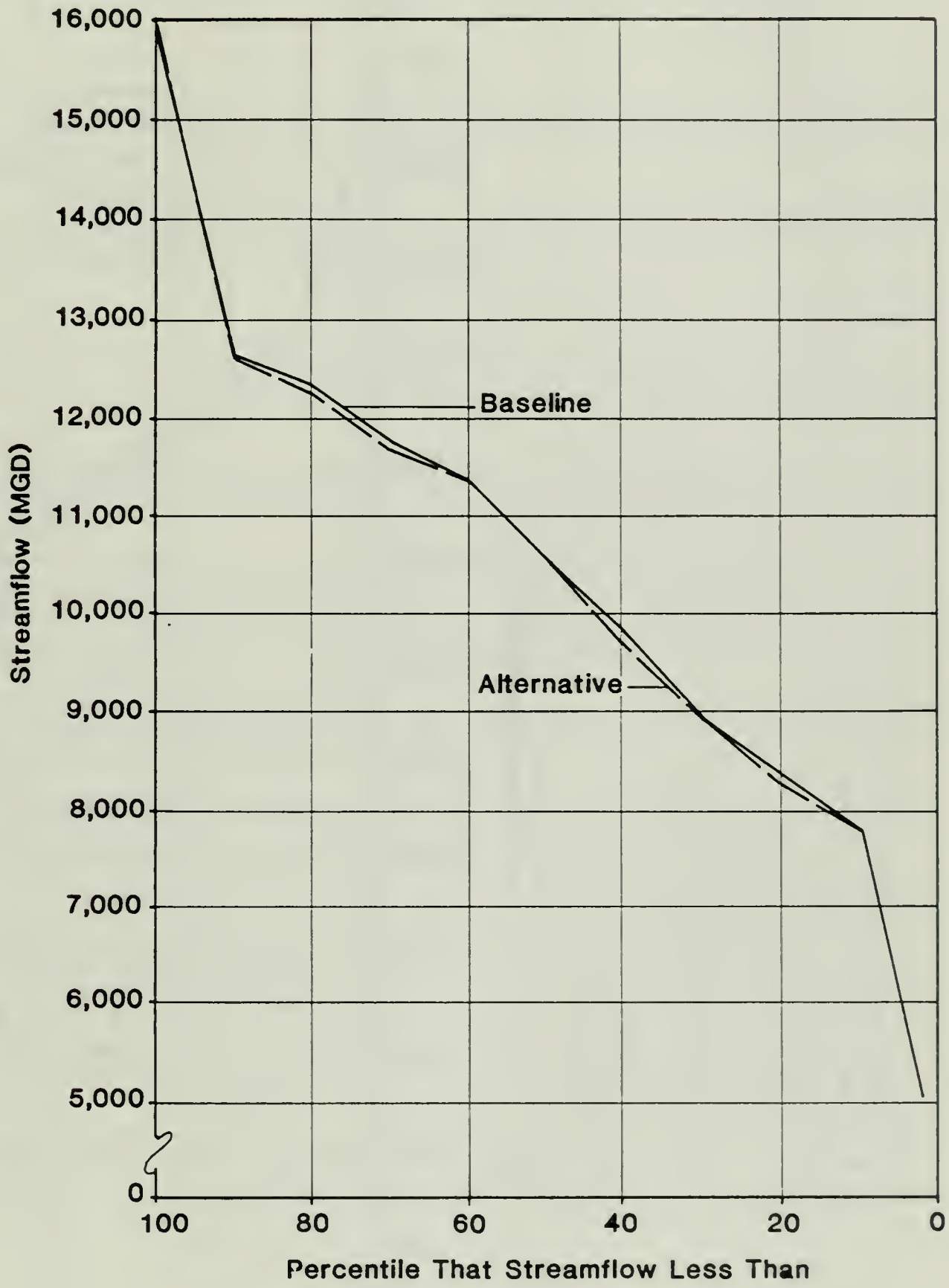


Figure 8.11-4.
Merrimack River Streamflow at Pawtucket Dam (Lowell)

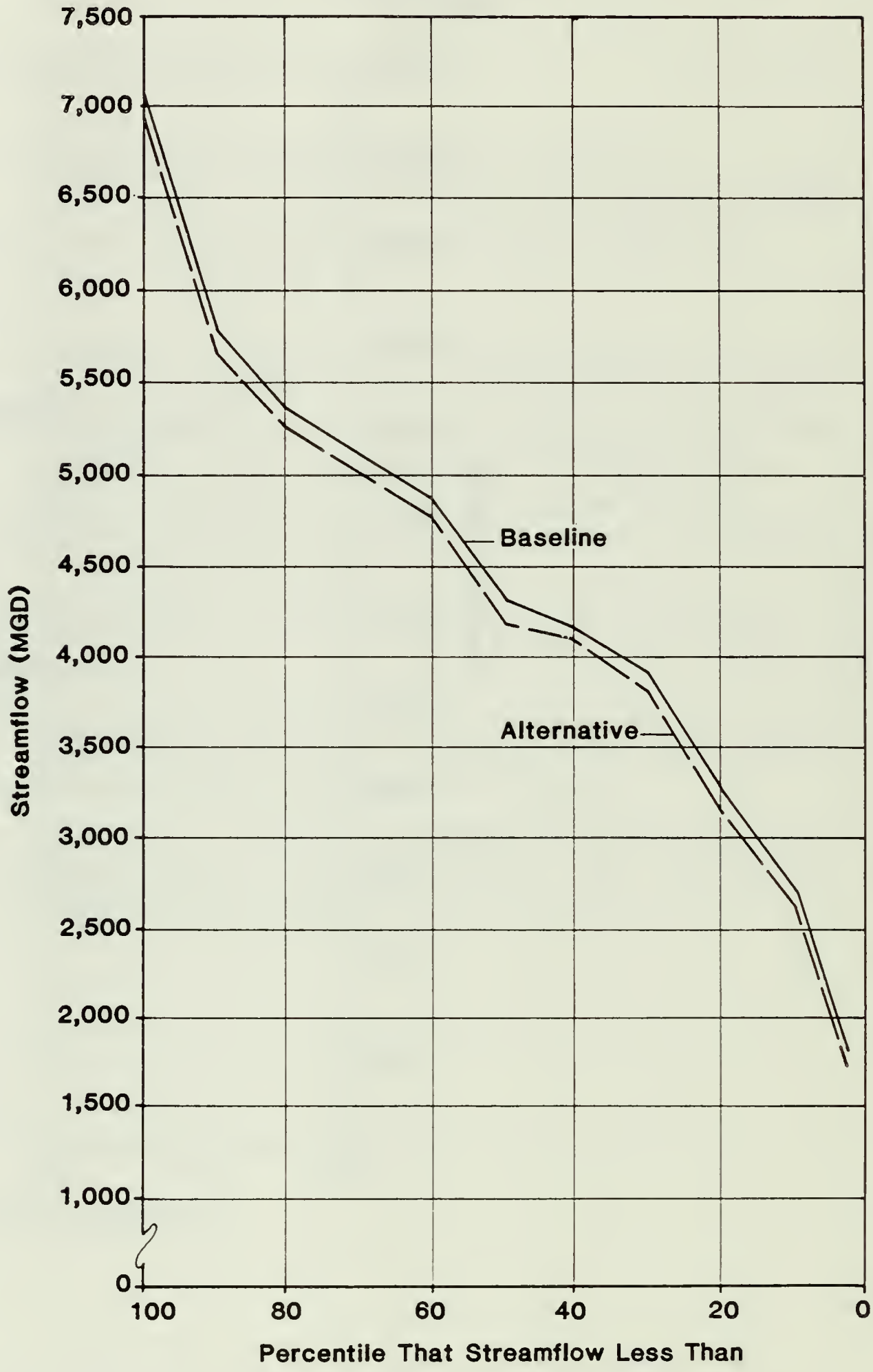


Figure 8.11-5.
Baseline and Merrimack Alternative Streamflows at Pawtucket Dam (Lowell)

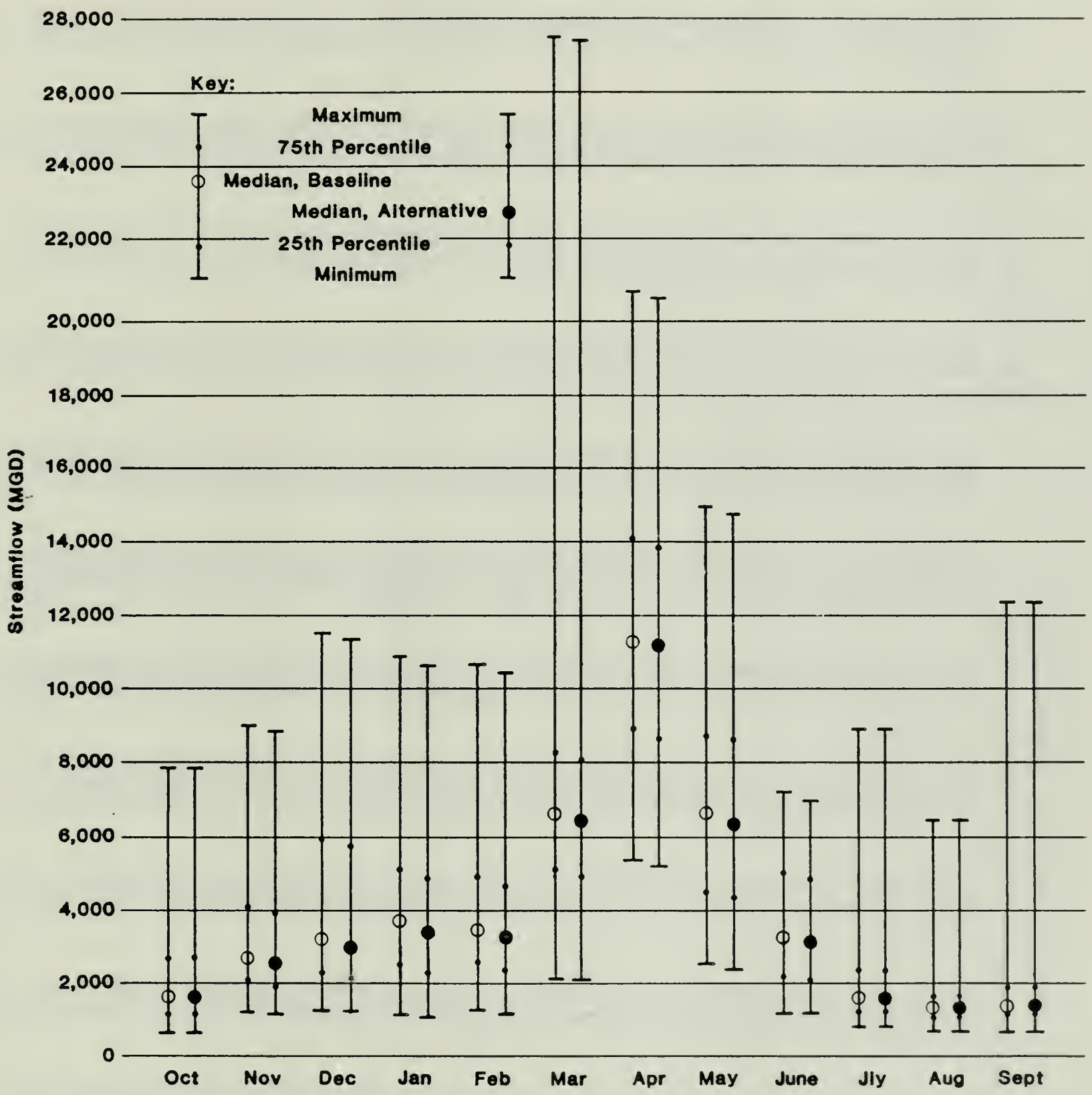


Table 8.11-21: DELTA VALUES OUTFLOW FROM QUABBIN RESERVOIR, MGD

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 1 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1936	0.0	0.0	0.0	0.0	0.0	0.0	-281.4	0.0	0.0	0.0	0.0	0.0	-23.1
8	1937	0.0	0.0	0.0	0.0	-70.8	0.0	-404.2	-293.1	0.0	0.0	0.0	0.0	-63.6
9	1938	0.0	0.0	0.0	0.0	0.0	0.0	-77.4	0.0	0.0	-266.7	0.0	-42.7	-32.5
10	1939	-115.6	0.0	-62.6	-3.1	-14.6	-42.6	0.0	0.0	0.0	0.0	0.0	0.0	-20.1
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1953	0.0	0.0	0.0	0.0	0.0	0.0	-536.1	-279.5	0.0	0.0	0.0	0.0	-67.8
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-60.9	0.0	0.0	0.0	0.0	-5.2
26	1955	0.0	0.0	-197.4	0.0	0.0	-37.8	0.0	0.0	0.0	0.0	0.0	0.0	-20.0
27	1956	-139.7	-293.1	0.0	-129.3	-16.5	-91.1	0.0	-88.8	-16.7	0.0	0.0	0.0	-64.8
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	-82.2	0.0	0.0	0.0	0.0	0.0	-6.8
31	1960	0.0	0.0	-81.4	-26.4	-123.3	0.0	-25.9	0.0	0.0	0.0	0.0	0.0	-20.7
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	-310.0	0.0	-4.5	0.0	0.0	0.0	-25.8
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-57.0	-15.1	-6.1
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	1974	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	1976	0.0	0.0	0.0	0.0	82.5	0.0	0.0	-50.6	0.0	0.0	0.0	0.0	2.0
48	1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	1978	0.0	0.0	0.0	-164.3	-56.0	-63.9	-18.4	0.0	0.0	0.0	0.0	0.0	-25.2
50	1979	0.0	0.0	0.0	0.0	0.0	-577.9	-284.4	0.0	0.0	0.0	0.0	0.0	-72.5
	AVER	-5.1	-5.9	-6.8	-6.5	-4.0	-16.3	-40.4	-15.5	-0.4	-5.3	-1.1	-1.2	-9.0

Table 8.11-22: DELTA VALUES STREAMFLOW - CHICOPEE R. AT INDIAN ORCHARD, PCT

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 3 1 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	98.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	96.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	94.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	92.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	88.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	86.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	84.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	82.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	78.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	76.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	74.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	72.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	68.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	66.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	64.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	62.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	58.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	56.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	54.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	52.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	48.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	46.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	42.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	38.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	34.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2
37	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.7
38	26.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.7
39	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.6
40	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.7
41	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8
42	18.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8
43	16.0	0.0	0.0	0.0	0.0	0.0	-1.4	0.0	0.0	0.0	0.0	0.0	0.0	-2.2
44	14.0	0.0	0.0	0.0	0.0	0.0	-7.1	0.0	0.0	0.0	0.0	0.0	0.0	-2.2
45	12.0	0.0	0.0	0.0	0.0	0.0	-8.7	0.0	0.0	0.0	0.0	0.0	0.0	-2.5
46	10.0	0.0	0.0	0.0	-2.3	-3.0	-19.6	-7.5	0.0	0.0	0.0	0.0	0.0	-3.7
47	8.0	0.0	0.0	0.0	-0.6	-2.8	-3.4	-19.7	-8.0	0.0	0.0	0.0	0.0	-4.2
48	6.0	0.0	0.0	-4.4	-3.8	-7.9	-7.8	-19.8	-8.0	0.0	0.0	0.0	0.0	-5.6
49	4.0	-11.6	0.0	-9.0	-13.7	-8.0	-8.5	-27.0	-16.9	-1.0	0.0	0.0	-1.1	-5.6
50	2.0	-12.9	-15.5	-18.2	-16.8	-13.4	-30.7	-31.5	-27.7	-3.3	-17.9	-53.8	-12.6	-5.7
	AVER	-0.5	-0.3	-0.6	-0.7	-0.6	-1.1	-2.7	-1.4	-0.1	-0.4	-1.1	-0.3	-0.8

Table 8.11-23: DELTA VALUES STREAMFLOW - CONN. R. AT THOMPSONVILLE, CT., PCT

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 3 0 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1931	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1932	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1933	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1934	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1935	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1936	0	0	0	0	0	0	-1	0	0	0	0	0	0
8	1937	0	0	0	0	-1	0	-2	-1	0	0	0	0	0
9	1938	0	0	0	0	0	0	0	0	0	-3	0	0	0
10	1939	-1	0	0	0	0	0	0	0	0	0	0	0	0
11	1940	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1941	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1942	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1943	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1944	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1945	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1946	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1947	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1948	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1949	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1950	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1951	0	0	0	0	0	0	0	0	0	0	0	0	0
23	1952	0	0	0	0	0	0	0	0	0	0	0	0	0
24	1953	0	0	0	0	0	0	-2	-1	0	0	0	0	0
25	1954	0	0	0	0	0	0	0	0	0	0	0	0	0
26	1955	0	0	-1	0	0	0	0	0	0	0	0	0	0
27	1956	-1	-1	0	-1	0	-1	0	0	0	0	0	0	0
28	1957	0	0	0	0	0	0	0	0	0	0	0	0	0
29	1958	0	0	0	0	0	0	0	0	0	0	0	0	0
30	1959	0	0	0	0	0	0	0	0	0	0	0	0	0
31	1960	0	0	0	0	-1	0	0	0	0	0	0	0	0
32	1961	0	0	0	0	0	0	-1	0	0	0	0	0	0
33	1962	0	0	0	0	0	0	0	0	0	0	0	0	0
34	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
35	1964	0	0	0	0	0	0	0	0	0	0	0	0	0
36	1965	0	0	0	0	0	0	0	0	0	0	0	0	0
37	1966	0	0	0	0	0	0	0	0	0	0	-2	0	0
38	1967	0	0	0	0	0	0	0	0	0	0	0	0	0
39	1968	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1969	0	0	0	0	0	0	0	0	0	0	0	0	0
41	1970	0	0	0	0	0	0	0	0	0	0	0	0	0
42	1971	0	0	0	0	0	0	0	0	0	0	0	0	0
43	1972	0	0	0	0	0	0	0	0	0	0	0	0	0
44	1973	0	0	0	0	0	0	0	0	0	0	0	0	0
45	1974	0	0	0	0	0	0	0	0	0	0	0	0	0
46	1975	0	0	0	0	0	0	0	0	0	0	0	0	0
47	1976	0	0	0	0	0	0	0	0	0	0	0	0	0
48	1977	0	0	0	0	0	0	0	0	0	0	0	0	0
49	1978	0	0	0	-1	-1	-1	0	0	0	0	0	0	0
50	1979	0	0	0	0	0	-1	-1	0	0	0	0	0	0
	AVER	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8.11-24: DELTA VALUES OUTFLOW FROM WACHUSETT RESERVOIR, MGD

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 1 1 2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1933	0.0	0.0	0.0	0.0	0.0	0.0	253.4	0.0	0.0	0.0	0.0	0.0	20.8
5	1934	0.0	0.0	0.0	0.0	0.0	0.0	143.3	1.8	0.0	0.0	0.0	0.0	11.9
6	1935	0.0	0.0	0.0	0.0	0.0	0.0	19.2	0.0	0.0	0.0	0.0	0.0	1.6
7	1936	0.0	0.0	0.0	0.0	0.0	33.3	120.4	0.0	0.0	0.0	0.0	0.0	12.7
8	1937	0.0	0.0	0.0	10.3	4.7	0.0	10.8	14.8	0.0	0.0	0.0	0.0	3.4
9	1938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-223.9	-18.4
10	1939	0.0	0.0	0.0	0.0	0.0	0.0	-127.9	0.0	0.0	0.0	0.0	0.0	-10.5
11	1940	0.0	0.0	0.0	0.0	0.0	0.0	120.4	69.2	0.0	0.0	0.0	0.0	15.8
12	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1942	0.0	0.0	0.0	0.0	0.0	33.2	1.0	0.0	0.0	0.0	0.0	0.0	2.9
14	1943	0.0	0.0	0.0	0.0	0.0	0.0	7.2	117.7	0.0	0.0	0.0	0.0	10.6
15	1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1945	0.0	0.0	0.0	0.0	0.0	13.6	75.2	98.6	0.0	0.0	0.0	0.0	15.7
17	1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1947	0.0	0.0	0.0	0.0	0.0	0.0	0.9	22.7	0.0	0.0	0.0	0.0	2.0
19	1948	0.0	0.0	0.0	0.0	0.0	0.0	8.3	85.2	42.4	0.0	0.0	0.0	11.4
20	1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1951	0.0	0.0	0.0	0.0	0.0	36.5	120.4	0.0	0.0	0.0	0.0	0.0	13.0
23	1952	0.0	0.0	0.0	61.3	32.5	40.0	121.2	0.0	0.0	0.0	0.0	0.0	21.1
24	1953	0.0	0.0	0.0	0.0	0.0	149.1	221.7	0.0	0.0	0.0	0.0	0.0	30.9
25	1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	1.1
26	1955	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1956	0.0	-7.1	0.0	0.0	0.0	0.0	-218.1	0.0	0.0	0.0	0.0	0.0	-18.5
28	1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1958	0.0	0.0	0.0	0.0	0.0	0.0	272.1	72.8	0.0	0.0	0.0	0.0	28.5
30	1959	0.0	0.0	0.0	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	0.0	1.1
31	1960	0.0	0.0	0.0	0.0	0.0	0.0	-204.2	0.0	0.0	0.0	0.0	0.0	-16.8
32	1961	0.0	0.0	0.0	0.0	0.0	0.0	166.6	0.0	0.0	0.0	0.0	0.0	13.7
33	1962	0.0	0.0	0.0	0.0	0.0	0.0	26.2	0.0	0.0	0.0	0.0	0.0	2.1
34	1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1965	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1966	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8	0.0	-0.2
38	1967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.3	0.0	0.0	0.0	0.0	7.2
39	1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1969	0.0	0.0	0.0	0.0	0.0	0.0	63.8	0.0	0.0	0.0	0.0	0.0	5.2
41	1970	0.0	0.0	0.0	0.0	0.0	0.0	161.0	0.0	0.0	0.0	0.0	0.0	13.2
42	1971	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1972	0.0	0.0	0.0	0.0	0.0	0.0	248.7	116.7	54.1	0.0	0.0	0.0	34.8
44	1973	0.0	0.0	0.0	0.0	75.5	160.3	166.1	61.9	0.0	0.0	0.0	0.0	38.3
45	1974	0.0	0.0	0.0	0.0	19.1	72.8	47.1	0.0	0.0	0.0	0.0	0.0	11.5
46	1975	0.0	0.0	0.0	0.0	0.0	0.0	69.1	0.0	0.0	0.0	0.0	0.0	5.7
47	1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	1977	0.0	0.0	0.0	0.0	0.0	29.7	143.0	0.0	0.0	0.0	0.0	0.0	14.3
49	1978	0.0	0.0	0.0	35.9	0.0	0.0	-46.5	0.0	0.0	0.0	0.0	0.0	-0.8
50	1979	0.0	0.0	0.0	11.8	0.0	290.9	0.0	0.0	0.0	0.0	0.0	0.0	25.7
	AVER	0.0	-0.1	0.0	2.4	2.6	17.2	40.1	15.2	1.9	0.0	-0.0	-4.5	6.2

Table 8.11-25: DELTA VALUES STREAMFLOW - MERRIMACK R. AT PAWTUCKET DAM

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	98.0	0	0	0	-2	0	0	0	0	0	0	0	0	-1
3	96.0	0	0	-2	-2	0	0	0	0	0	0	0	0	-1
4	94.0	0	-2	-3	-3	0	0	0	0	0	0	0	0	-1
5	92.0	0	-2	-3	-3	-2	0	0	0	0	0	0	0	-1
6	90.0	0	-2	-3	-3	-2	0	0	0	0	0	0	0	-2
7	88.0	0	-3	-3	-4	-3	0	0	0	0	0	0	0	-2
8	86.0	0	-3	-3	-4	-3	0	0	0	0	0	0	0	-2
9	84.0	0	-3	-3	-4	-3	-1	-1	0	0	0	0	0	-2
10	82.0	0	-3	-3	-4	-3	-1	-1	-1	0	0	0	0	-2
11	80.0	0	-3	-4	-4	-3	-1	-1	-1	0	0	0	0	-2
12	78.0	0	-3	-4	-4	-4	-1	-1	-1	-1	0	0	0	-2
13	76.0	0	-3	-4	-5	-4	-2	-1	-1	-1	0	0	0	-2
14	74.0	0	-3	-4	-5	-4	-2	-1	-1	-1	0	0	0	-2
15	72.0	0	-3	-4	-5	-4	-2	-1	-2	-2	0	0	0	-2
16	70.0	0	-3	-4	-5	-5	-2	-1	-2	-2	0	0	0	-2
17	68.0	0	-3	-4	-5	-5	-2	-1	-2	-2	0	0	0	-2
18	66.0	0	-3	-4	-5	-5	-2	-1	-2	-3	0	0	0	-3
19	64.0	0	-3	-5	-5	-5	-2	-1	-2	-3	0	0	0	-3
20	62.0	0	-3	-5	-5	-5	-2	-1	-2	-3	0	0	0	-3
21	60.0	0	-4	-6	-5	-6	-2	-1	-3	-3	0	0	0	-3
22	58.0	0	-4	-6	-6	-6	-2	-1	-3	-3	0	0	0	-3
23	56.0	0	-4	-6	-6	-6	-2	-2	-3	-3	0	0	0	-3
24	54.0	0	-4	-6	-6	-6	-3	-2	-3	-3	0	0	0	-3
25	52.0	0	-4	-6	-6	-7	-3	-2	-3	-3	0	0	0	-3
26	50.0	0	-4	-7	-6	-7	-3	-2	-3	-3	0	0	0	-3
27	48.0	0	-4	-7	-6	-7	-3	-2	-3	-3	0	0	0	-3
28	46.0	0	-4	-7	-6	-7	-3	-2	-4	-4	0	0	0	-3
29	44.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
30	42.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
31	40.0	0	-5	-7	-8	-7	-3	-2	-4	-4	0	0	0	-3
32	38.0	0	-5	-8	-8	-7	-3	-2	-4	-4	0	0	0	-3
33	36.0	0	-5	-8	-8	-7	-3	-2	-4	-4	0	0	0	-3
34	34.0	0	-5	-8	-8	-8	-3	-2	-4	-4	0	0	0	-3
35	32.0	0	-5	-8	-8	-8	-3	-2	-4	-4	0	0	0	-3
36	30.0	0	-5	-8	-8	-8	-3	-2	-5	-4	0	0	0	-3
37	28.0	0	-5	-8	-8	-8	-3	-2	-5	-4	0	0	0	-3
38	26.0	0	-5	-8	-9	-8	-3	-2	-5	-4	0	0	0	-3
39	24.0	0	-5	-9	-9	-8	-3	-2	-5	-4	0	0	0	-3
40	22.0	0	-5	-9	-9	-9	-3	-3	-5	-4	0	0	0	-4
41	20.0	0	-5	-9	-9	-9	-3	-3	-5	-4	0	0	0	-4
42	18.0	0	-6	-9	-10	-9	-4	-3	-5	-5	0	0	0	-4
43	16.0	0	-6	-10	-10	-9	-4	-3	-5	-5	0	0	0	-4
44	14.0	0	-6	-10	-10	-9	-4	-3	-5	-5	0	0	0	-4
45	12.0	0	-6	-10	-10	-10	-4	-3	-5	-5	0	0	0	-4
46	10.0	0	-6	-10	-11	-11	-4	-3	-5	-5	0	0	0	-4
47	8.0	0	-6	-11	-11	-12	-4	-3	-5	-5	0	0	0	-4
48	6.0	0	-7	-12	-12	-12	-4	-4	-5	-6	0	0	0	-4
49	4.0	0	-7	-12	-12	-12	-4	-4	-5	-6	0	0	0	-4
50	2.0	0	-7	-13	-13	-13	-5	-4	-6	-6	0	0	-2	-4
	AVER	0	-4	-6	-6	-6	-2	-2	-3	-3	0	0	0	-3

Table 8.11-26: DELTA VALUES STREAMFLOW - MERRIMACK R. AT LOWELL, PCT

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 3 0 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	98.0	0	0	0	-2	0	0	0	0	0	0	0	0	-1
3	96.0	0	0	-2	-2	0	0	0	0	0	0	0	0	-1
4	94.0	0	-2	-3	-3	0	0	0	0	0	0	0	0	-1
5	92.0	0	-2	-3	-3	-2	0	0	0	0	0	0	0	-1
6	90.0	0	-2	-3	-3	-2	0	0	0	0	0	0	0	-1
7	88.0	0	-2	-3	-3	-3	0	0	0	0	0	0	0	-1
8	86.0	0	-2	-3	-3	-3	0	0	0	0	0	0	0	-2
9	84.0	0	-2	-3	-3	-3	-1	0	0	0	0	0	0	-2
10	82.0	0	-3	-3	-4	-3	-1	0	-1	0	0	0	0	-2
11	80.0	0	-3	-3	-4	-3	-1	0	-1	0	0	0	0	-2
12	78.0	0	-3	-4	-4	-3	-1	-1	-1	-1	0	0	0	-2
13	76.0	0	-3	-4	-4	-3	-1	-1	-1	-1	0	0	0	-2
14	74.0	0	-3	-4	-4	-4	-1	-1	-1	-1	0	0	0	-2
15	72.0	0	-3	-4	-4	-4	-2	-1	-1	-2	0	0	0	-2
16	70.0	0	-3	-4	-4	-4	-2	-1	-2	-2	0	0	0	-2
17	68.0	0	-3	-4	-4	-5	-2	-1	-2	-2	0	0	0	-2
18	66.0	0	-3	-4	-4	-5	-2	-1	-2	-3	0	0	0	-2
19	64.0	0	-3	-4	-4	-5	-2	-1	-2	-3	0	0	0	-2
20	62.0	0	-3	-5	-4	-5	-2	-1	-2	-3	0	0	0	-2
21	60.0	0	-3	-5	-5	-5	-2	-1	-2	-3	0	0	0	-2
22	58.0	0	-3	-5	-5	-5	-2	-1	-3	-3	0	0	0	-2
23	56.0	0	-4	-6	-5	-5	-2	-1	-3	-3	0	0	0	-2
24	54.0	0	-4	-6	-5	-6	-2	-2	-3	-3	0	0	0	-2
25	52.0	0	-4	-6	-6	-6	-2	-2	-3	-3	0	0	0	-3
26	50.0	0	-4	-6	-6	-6	-2	-2	-3	-3	0	0	0	-3
27	48.0	0	-4	-6	-6	-6	-2	-2	-3	-3	0	0	0	-3
28	46.0	0	-4	-7	-6	-6	-2	-2	-3	-3	0	0	0	-3
29	44.0	0	-4	-7	-6	-6	-2	-2	-4	-3	0	0	0	-3
30	42.0	0	-4	-7	-6	-6	-2	-2	-4	-3	0	0	0	-3
31	40.0	0	-4	-7	-7	-6	-3	-2	-4	-3	0	0	0	-3
32	38.0	0	-4	-7	-7	-6	-3	-2	-4	-3	0	0	0	-3
33	36.0	0	-4	-7	-7	-6	-3	-2	-4	-4	0	0	0	-3
34	34.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
35	32.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
36	30.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
37	28.0	0	-4	-7	-7	-7	-3	-2	-4	-4	0	0	0	-3
38	26.0	0	-5	-8	-7	-7	-3	-2	-4	-4	0	0	0	-3
39	24.0	0	-5	-8	-8	-8	-3	-2	-4	-4	0	0	0	-3
40	22.0	0	-5	-8	-8	-8	-3	-2	-4	-4	0	0	0	-3
41	20.0	0	-5	-8	-8	-8	-3	-3	-4	-4	0	0	0	-3
42	18.0	0	-5	-9	-9	-8	-3	-3	-4	-4	0	0	0	-3
43	16.0	0	-5	-9	-9	-8	-3	-3	-5	-4	0	0	0	-3
44	14.0	0	-5	-9	-9	-8	-3	-3	-5	-4	0	0	0	-3
45	12.0	0	-5	-9	-9	-9	-3	-3	-5	-5	0	0	0	-3
46	10.0	0	-6	-9	-10	-9	-3	-3	-5	-5	0	0	0	-3
47	8.0	0	-6	-10	-10	-10	-4	-3	-5	-5	0	0	0	-3
48	6.0	0	-6	-10	-10	-10	-4	-3	-5	-5	0	0	0	-4
49	4.0	0	-6	-11	-11	-11	-4	-4	-5	-5	0	0	0	-4
50	2.0	0	-7	-12	-12	-11	-5	-4	-6	-5	0	0	-2	-4
	AVER	0	-4	-6	-6	-5	-2	-1	-3	-3	0	0	0	-2

Table 8.11-27: DELTA VALUES STREAMFLOW - MERRIMACK R. AT LAWRENCE DAM

RUN HY-14 06/21/85 MERRIMACK ALTERNATIVE (235 MGD TREATMENT PLANT) IOA= -1 0 0 3 2 -2

NY	HYYR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVER
1	100.0	0.0	0.0	0.0	0.0	0.0	0.35	0.21	0.0	0.0	0.0	0.0	0.0	-0.33
2	98.0	0.0	0.0	0.0	-1.63	0.0	0.0	0.09	0.0	0.0	0.0	0.0	0.0	-0.81
3	96.0	0.0	0.0	-1.86	-1.95	0.0	0.0	0.08	0.0	0.0	0.0	0.0	0.0	-1.15
4	94.0	0.0	-2.10	-2.49	-2.67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.17
5	92.0	0.0	-2.16	-2.60	-2.79	-1.47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.17
6	90.0	0.0	-2.17	-2.85	-2.79	-1.87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.39
7	88.0	0.0	-2.28	-2.91	-3.07	-2.52	-0.40	-0.08	0.0	0.0	0.0	0.0	0.0	-1.45
8	86.0	0.0	-2.29	-2.99	-3.24	-2.54	-0.41	-0.34	0.0	0.0	0.0	0.0	0.0	-1.52
9	84.0	0.0	-2.45	-3.00	-3.40	-2.57	-0.51	-0.46	0.0	0.0	0.0	0.0	0.0	-1.55
10	82.0	0.0	-2.57	-3.02	-3.64	-2.93	-0.56	-0.47	-0.93	-0.12	0.0	0.0	0.0	-1.56
11	80.0	0.0	-2.57	-3.21	-3.67	-3.03	-0.90	-0.47	-0.98	-0.37	0.0	0.0	0.0	-1.69
12	78.0	0.0	-2.65	-3.44	-3.88	-3.28	-1.08	-0.50	-1.08	-0.53	0.0	0.0	0.0	-1.71
13	76.0	0.0	-2.67	-3.46	-3.96	-3.36	-1.43	-0.58	-1.32	-0.62	0.0	0.0	0.0	-1.81
14	74.0	0.0	-2.72	-3.50	-4.01	-3.53	-1.45	-0.63	-1.37	-0.70	0.0	0.0	0.0	-1.85
15	72.0	0.0	-2.73	-3.51	-4.06	-3.65	-1.61	-0.67	-1.40	-1.50	0.0	0.0	0.0	-1.86
16	70.0	0.0	-2.82	-3.56	-4.09	-4.10	-1.75	-0.67	-1.55	-1.55	0.0	0.0	0.0	-2.09
17	68.0	0.0	-2.91	-3.65	-4.14	-4.41	-1.84	-0.75	-1.58	-2.02	0.0	0.0	0.0	-2.09
18	66.0	0.0	-3.00	-3.98	-4.27	-4.53	-1.87	-0.78	-1.60	-2.54	0.0	0.0	0.0	-2.28
19	64.0	0.0	-3.11	-3.99	-4.30	-4.56	-1.89	-0.85	-1.70	-2.59	0.0	0.0	0.0	-2.30
20	62.0	0.0	-3.13	-4.49	-4.40	-4.65	-1.90	-0.92	-2.15	-2.67	0.0	0.0	0.0	-2.32
21	60.0	0.0	-3.18	-4.92	-4.72	-4.81	-1.91	-1.27	-2.37	-2.79	0.0	0.0	0.0	-2.40
22	58.0	0.0	-3.27	-5.14	-5.02	-4.83	-1.95	-1.37	-2.55	-2.91	0.0	0.0	0.0	-2.40
23	56.0	0.0	-3.50	-5.40	-5.14	-5.03	-2.15	-1.37	-2.58	-2.96	0.0	0.0	0.0	-2.41
24	54.0	0.0	-3.64	-5.59	-5.18	-5.60	-2.21	-1.51	-2.61	-3.06	0.0	0.0	0.0	-2.46
25	52.0	0.0	-3.64	-5.87	-5.45	-5.71	-2.21	-1.51	-2.92	-3.07	0.0	0.0	0.0	-2.49
26	50.0	0.0	-3.65	-5.92	-5.62	-5.80	-2.25	-1.54	-3.01	-3.15	0.0	0.0	0.0	-2.56
27	48.0	0.0	-3.67	-6.19	-5.70	-5.89	-2.29	-1.63	-3.14	-3.20	0.0	0.0	0.0	-2.57
28	46.0	0.0	-3.72	-6.48	-5.93	-5.96	-2.37	-1.63	-3.40	-3.24	0.0	0.0	0.0	-2.61
29	44.0	0.0	-3.84	-6.48	-6.02	-6.05	-2.40	-1.64	-3.50	-3.29	0.0	0.0	0.0	-2.67
30	42.0	0.0	-3.88	-6.57	-6.21	-6.23	-2.43	-1.89	-3.51	-3.39	0.0	0.0	0.0	-2.70
31	40.0	0.0	-4.08	-6.58	-6.55	-6.25	-2.49	-1.93	-3.67	-3.41	0.0	0.0	0.0	-2.70
32	38.0	0.0	-4.18	-6.86	-6.56	-6.25	-2.56	-1.95	-3.77	-3.41	0.0	0.0	0.0	-2.74
33	36.0	0.0	-4.21	-7.06	-6.65	-6.34	-2.62	-1.98	-3.82	-3.47	0.0	0.0	0.0	-2.75
34	34.0	0.0	-4.30	-7.18	-6.75	-6.39	-2.69	-2.02	-3.92	-3.53	0.0	0.0	0.0	-2.78
35	32.0	0.0	-4.33	-7.19	-6.88	-6.46	-2.69	-2.05	-3.99	-3.54	0.0	0.0	0.0	-2.83
36	30.0	0.0	-4.40	-7.28	-6.91	-6.97	-2.81	-2.05	-4.06	-3.60	0.0	0.0	0.0	-2.84
37	28.0	0.0	-4.48	-7.32	-7.06	-7.02	-2.90	-2.09	-4.06	-3.62	0.0	0.0	0.0	-2.86
38	26.0	0.0	-4.51	-7.56	-7.15	-7.20	-2.92	-2.15	-4.09	-3.65	0.0	0.0	0.0	-3.03
39	24.0	0.0	-4.58	-7.83	-7.70	-7.46	-2.97	-2.22	-4.20	-3.84	0.0	0.0	0.0	-3.06
40	22.0	0.0	-4.59	-7.99	-7.81	-7.59	-3.00	-2.40	-4.21	-3.92	0.0	0.0	0.0	-3.10
41	20.0	0.0	-4.82	-8.17	-7.85	-7.68	-3.02	-2.51	-4.33	-4.02	0.0	0.0	0.0	-3.22
42	18.0	0.0	-5.06	-8.62	-8.39	-7.70	-3.02	-2.51	-4.34	-4.16	0.0	0.0	0.0	-3.25
43	16.0	0.0	-5.10	-8.81	-8.49	-7.88	-3.08	-2.55	-4.52	-4.22	0.0	0.0	0.0	-3.32
44	14.0	0.0	-5.16	-9.20	-8.50	-7.98	-3.10	-2.57	-4.54	-4.22	0.0	0.0	0.0	-3.35
45	12.0	0.0	-5.26	-9.34	-8.86	-8.87	-3.26	-2.93	-4.59	-4.61	0.0	0.0	0.0	-3.39
46	10.0	0.0	-5.44	-9.34	-9.88	-9.35	-3.30	-2.99	-4.68	-4.82	0.0	0.0	0.0	-3.40
47	8.0	0.0	-5.68	-9.97	-9.92	-9.80	-3.47	-3.03	-4.79	-4.85	0.0	0.0	0.0	-3.41
48	6.0	0.0	-6.12	-9.99	-10.11	-10.22	-3.57	-3.27	-4.80	-4.97	0.0	0.0	0.0	-3.50
49	4.0	0.0	-6.35	-10.53	-10.58	-10.38	-3.78	-3.60	-4.96	-5.05	0.0	0.0	0.0	-3.65
50	2.0	0.0	-6.43	-11.35	-11.63	-10.46	-4.54	-3.82	-5.73	-5.07	0.0	-0.19	-1.50	-3.71
	AVER	0.0	-3.59	-5.70	-5.70	-5.34	-2.02	-1.48	-2.65	-2.57	0.0	-0.00	-0.03	-2.41

8.12 FACILITY DESIGN

8.12.1 Descriptions of the Facility

I. Design Yield

- Transfer System. The Merrimack River Alternative involves the transfer of water from the Merrimack River to the MDC transmission and distribution system during periods of high flow in the river. Water would be diverted through intake screens located in the river near Tyngsborough, pumped to and treated at a water treatment plant, conveyed by gravity through a tunnel to the vicinity of Spot Pond in Stoneham, and pumped to boost its pressure to a level sufficient to deliver the water into MDC transmission and distribution system. Drawing Nos. SK-M-001 through SK-M-004 show the proposed facilities in plan and profile. Drawing No. SK-M-005 shows details of the proposed pumping facilities at Spot Pond. Drawing Nos. SK-M-006 and SK-M-007 show details of the proposed water treatment plant at the Merrimack River. Drawings are included in Appendix 8-1.

  A preliminary analysis was made of the costs of a tunnel versus a pipeline for this alternative. The results are included as an appendix. Although the cost of a tunnel is estimated to exceed the cost of a pipeline by approximately 17 percent, a tunnel is recommended for this alternative for several reasons enumerated in the appendix.

- Diversion Requirements. The MDC diversion of water from the Merrimack River will occur only during periods of high flow in the river and when Quabbin and Wachusett Reservoirs are less than 98 percent full. Minimum streamflow requirements have been assessed in earlier studies (USCOE, 1977) for: (1) promoting the upstream migration of anadromous fish, (2) allowing effective dilution of wastewater effluents discharged to the river, and (3) operations of downstream hydropower facilities at Lowell and Lawrence (see Table 8.12-1). Under this study, attempts were made to develop current estimates of downstream flow requirements. Those results are shown in Table 8.12-2. While earlier estimates of streamflow requirements for anadromous fish and water quality still appear to be appropriate, the streamflow requirements for downstream hydroelectric power generation has substantially increased. A new hydropower facility has been installed in Lawrence and one is under construction in Lowell.

TABLE 8.12-1: ALLIED WATER RESOURCE FLOW NEEDS* (CFS)
MERRIMACK RIVER AT LOWELL, MASSACHUSETTS (USCOE, 1977)

Month	Water Quality	Existing Hydroelectric Power	Anadromous Fish Restoration	Average Monthly Flow
January	980	3,500	2,000	5,000
February	980	3,500	2,000	6,200
March	980	3,500	6,000	10,400
April	980	3,500	6,000	17,000
May	980	3,500	4,000	9,600
June	980	3,500	4,000	5,000
July	980	3,500	3,500	3,000
August	980	3,500	3,500	2,400
September	980	3,500	3,500	2,200
October	980	3,500	3,500	3,000
November	980	3,500	3,500	3,000
December	980	3,500	2,000	5,400

"*Note: Figures shown are flow rates considered satisfactory for purposes shown. The values presented, however, are not additive. For example, a flow rate of 6,000 cfs in March would satisfy not only the anadromous fish program requirements but those also for water quality and hydroelectric power."

TABLE 8.12-2: UPDATED ALLIED WATER FLOW NEEDS[1] (CFS)
MERRIMACK RIVER AT LOWELL, MASSACHUSETTS

Month	Water Quality[2]	Hydroelectric Power[3] Current / Future	Anadromous Fish Restoration Program[4]
January	980	11,000 / 12,000	2,000 or less
February	980	11,000 / 12,000	2,000 or less
March	980	11,000 / 12,000	6,000 or less
April	980	11,000 / 12,000	6,000 or less
May	980	11,000 / 12,000	4,000 or less
June	980	11,000 / 12,000	4,000 or less
July	980	11,000 / 12,000	3,500 or less
August	980	11,000 / 12,000	3,500 or less
September	980	11,000 / 12,000	3,500 or less
October	980	11,000 / 12,000	3,500 or less
November	980	11,000 / 12,000	3,500 or less
December	980	11,000 / 12,000	2,000 or less

[1] The values presented are not additive. For example, a flow rate of 11,000/12,000 cfs is sufficient to meet all three requirements.

[2] Same number as was presented in COE NEWS study of 1977. This number appears reasonable based on discussions with DEQE Division of Water Pollution Control which assesses a minimum flow value of 987 cfs (7 day, 10 year discharge) just downstream of Lowell.

[3] From Locks and Canals, Inc., Lowell, Massachusetts.

[4] Numerical values were developed for COE NEWS study of 1977 by Jason M. Cortell and Associates, Inc., Wellesley Hills, Massachusetts. Based on discussions with this company, the required flow needs may now be less since the quality of the Merrimack River water has improved over the last 10 years.

If fully projected hydropower requirements were used as a constraint for the diversion, the diversion would be limited to only a few months per year, causing the yield of the alternative to be very small and/or the diversion rate to be very high. An analysis of diversion impacts indicates a small percentage decrease in hydropower production as a result of diverting when flow is less than 11,000-12,000 cfs. Therefore, full hydropower requirements have not been used as a constraint. Instead, the impact on hydropower generation (loss in revenues) was assessed. The impact is presented in Section 8.14.

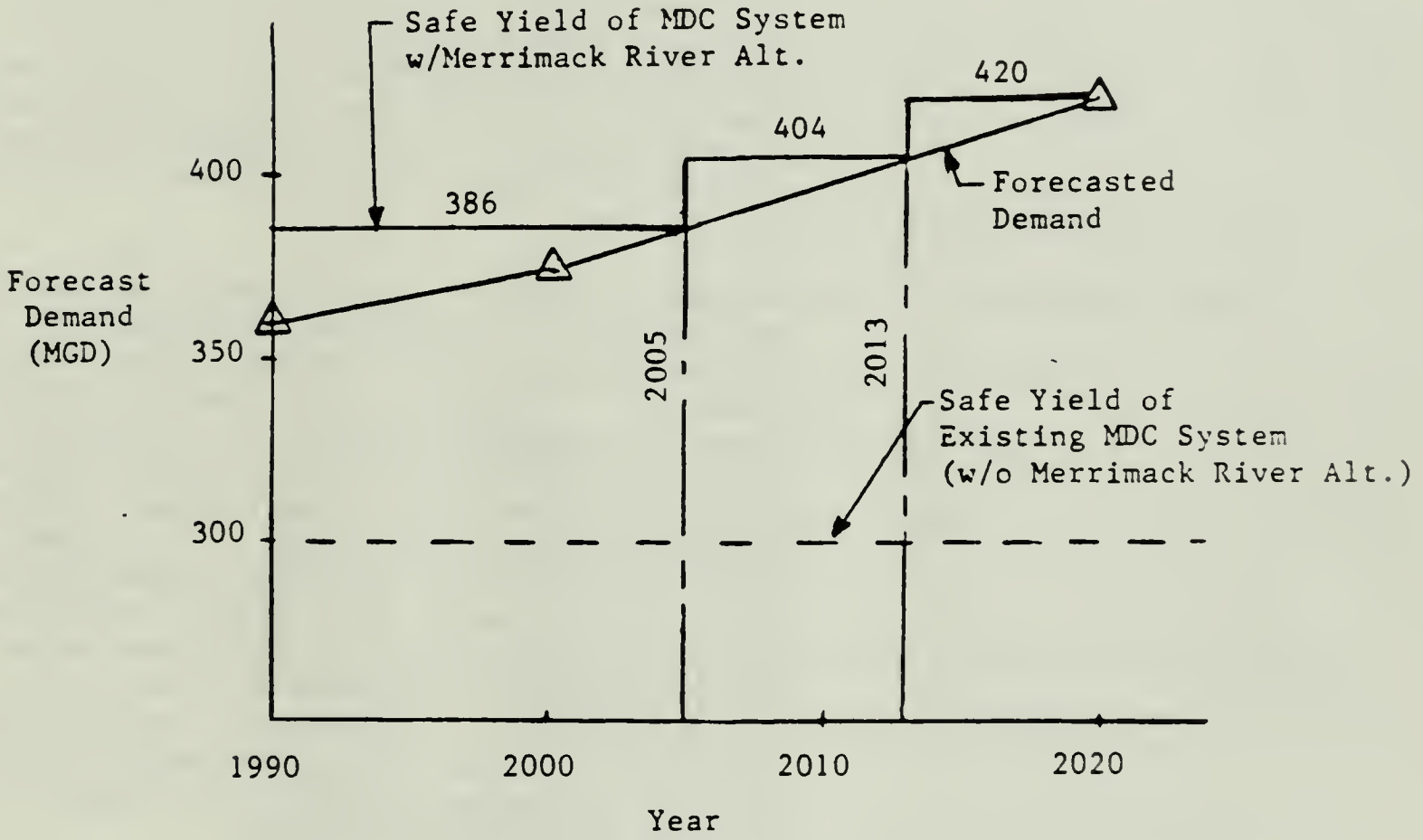
- Yield. The hydrologic model for the Merrimack River Alternative, developed by Arthur D. Little, Inc., is described under Section 8.11. Results of the computer simulations indicate that the maximum potential yield is greater than the forecasted water need for the year 2020 of 120 MGD. Thus, the alternative was sized to provide an average annual yield of 120 MGD. Review of preliminary results showed very few days on which the diversion could be made during the months of July, August, September, and October. Therefore, the diversion period was limited to eight months, November through June. During this eight month period, diversion will only be permitted when streamflow exceeds the minimum flow required (for anadromous fish and wastewater dilution) and Quabbin Reservoir and the Wachusett Reservoir are less than 98 percent full. On average, there are 186 days per year on which all of the above constraints are satisfied. To provide an average annual yield of 120 MGD, the capacities of the water treatment and pumping facilities and the maximum diversion rate would need to be 235 MGD.

- Operations. The Merrimack River Alternative would be active only eight months per year (November through June). Diversion would be made when streamflow exceeds the minimum flow requirement and Wachusett and Quabbin Reservoirs are less than 98 percent full. Diversion would be made at 235 MGD for 186 days per year, on the average. This diversion rate is equivalent to an average annual yield of 120 MGD, which is the forecasted water need for the year 2020.

  Prior to the year 2020, this alternative, if implemented as conceptually designed, would operate at less than full capacity. A suggested plan would be to construct the alternative (for the most part, the water treatment plant) in three stages. Initially, in year 1990, the alternative would be constructed for a transfer rate of 165 MGD. The safe yield at this size would be 86 MGD. By year 2006, a 35 MGD expansion

would be needed to increase the safe yield to 104 MGD. Finally, by year 2013, the remaining 35 MGD of capacity would be constructed. The ultimate (year 2020) safe yield would be 120 MGD. Figure 8.12-1 shows the projected demand on the MDC system for years 1990 to 2020, and the safe yield of the MDC system, with and without the Merrimack River Alternative.

FIGURE 8.12-1



At the beginning of each operating season, approximately November 1st, the water treatment plant would be started and initially, water would be returned to the river. This would allow for startup, chemical balancing and effluent testing.

Once the water treatment plant has been started and the chemical systems are set, treated water would be directed to the tunnel system for transport to the proposed Spot Pond Pumping Facility. It may be necessary to heavily chlorinate the first batch of water directed to the tunnel system to disinfect the system. This water will be used to displace

approximately 80 million gallons of stale water which will be in the tunnel system at the start of operations. The stale water will be diverted into Spot Pond for re-aeration and disinfected with chlorine as it is pumped from Spot Pond through the existing Spot Pond pumping station.

It will take approximately two days to completely displace the stale water in the tunnel system with fresh water. After completing displacement and disinfection operations, water will begin to be pumped to the MDC transmission and distribution system at Shaft 9A. The start up of this part of the system would be phased to allow time for the flow of water from Quabbin and Wachusett to be reduced as the diversion from the Merrimack River is increased. Pumps at the proposed Spot Pond Pumping Facility would be started one at a time, allowing a sufficient amount of time for flows in the MDC system to balance between pump starts.

The MDC has run the computer model of its transmission and distribution system to check hydraulic conditions in the system with the Merrimack River Alternative connected. A report on the results is included as an appendix. Although phasing this alternative in and out will require close attention and coordination, there appears to be no major problems with adding this alternative to the MDC system. The system design should include a sophisticated communications and control system which would allow a smooth change in flows from Quabbin and Wachusett Reservoirs as the Merrimack River Alternative is brought into and taken out of operation. In addition, the need for supplemental piping between the existing Spot Pond pumping station and the MDC's distribution system near Shaft 9A should be considered.

II. Treatment and Transport Requirements

- Diversion Facilities.

The diversion facilities from the Merrimack River to the MDC transmission and distribution system are shown on the appended drawings. Facilities include:

- Eight, 72-inch diameter tee-type intake screens and piping to raw water pumping station,

- Raw water pumping station, including wet well, building, four low head vertical turbine pumps (each 54,400 gpm at 40 feet TDH), air backwash equipment and maintenance shop,

- Water treatment plant, sized to deliver 235 MGD of water, which may be constructed in phases,

- Approximately 136,900 linear feet of 10-foot diameter tunnel from the Merrimack River to MDC Shaft 9A,

- Nine shafts, three 8-foot I.D. and six 18-foot I.D.,

- Pumping facility at Spot Pond, consisting of a forebay, underground pump cavern, two 18-foot diameter access shafts, and above ground support facilities; pumps include: five (33,900 gpm at 270 feet TDH) pumps, one (28,000 gpm at 180 feet TDH) pump, two sump pumps (1,000 gpm at 170 feet TDH), and one general service sump pump (50 gpm at 170 feet TDH),

- Pipeline and outlet structure at Spot Pond,

- Connection to Northern Low Service System,

- Connection to Fells Reservoir,

- Connection to MDC Shaft 9A,

- Modifications to existing MDC system at Shaft 5 and Spot Pond, and

- Approximately 14,500 linear feet of 48-inch diameter pipeline from the existing Spot Pond pumping station to the existing MDC distribution system in the vicinity of Shaft 9A.

- Treatment. The quality of the Merrimack River water to be diverted to the MDC transmission and distribution system has been assessed. That assessment is presented in Section 8.20 of this report. Primary drinking water standards are exceeded for turbidity and coliform, and secondary standards are exceeded for iron, manganese, and phenols. Chromium and cadmium have been measured at significant levels, though less than the regulated maximum contaminant levels (MCL). Also, concentrations of PCB and toxic organics (anthracene, fluoranthene, pyrene, toluene) have been measured in the water and the sediments, respectively. Thus, it has been recommended that water treatment also be considered for chromium, cadmium, PCB, and toxic organics until further data is available. No change is expected in the turbidity, coliform, iron and manganese levels through the year 2020. A prediction of future trends

of organics was not possible because of limited existing data.

Required treatment processes include conventional treatment to control turbidity, iron, manganese, and trace metal concentrations, and advanced treatment (activated carbon) for removal of phenols, PCB and toxic organics.

The Lowell Water Treatment Plant was contacted to obtain information on their treatment operations, specifically their use of advanced treatment processes. The Lowell Plant includes dual-media filters followed by granular activated carbon (GAC) filters. The purpose of the GAC filters is to remove taste, color and any halogenated hydrocarbons that may be present in the water. Halogenated hydrocarbons have not actually been measured in the raw water, but GAC filtration is used as a precautionary measure.

Based on the above information, a treatment system consisting of conventional treatment followed by GAC filtration is recommended. Unit operations are as follows:

- pH adjustment with lime
- coagulation with alum
- flocculation
- sedimentation
- dual media filtration
- GAC filtration
- ammonia addition
- chlorination and fluoridation

These operations should reduce potential contaminants identified above to acceptable levels. However, pilot plant testing would be required to demonstrate the need for and adequacy of these treatment steps before implementation of this alternative. A generalized flow diagram of the water treatment plant is shown in SK-M-006. Because of the two filter arrangement and relatively low level of treatment required, a filter loading rate of 4.3 gpm/sq. ft. has been used in sizing the filters. This rate is subject to pilot plant testing during detailed design.

Storage of finished water would be provided for backwashing the filters and providing a constant flow to the tunnel. Filter backwash water would be conveyed to the surge basin and then returned to the head of the treatment plant. Chemical sludge would be partially dewatered in a thickener, followed by a centrifuge before disposal in a landfill. The decant

water from each of these units would be returned to the head of the treatment plant.

Facilities required to provide the above treatment steps are shown in the attached water treatment plant layout (Drawing SK-M-007). The water treatment facility would be located in Tyngsborough, on the west bank of the Merrimack River, approximately one-half mile north of the Tyngsborough Bridge. This is the same site that was selected by COE for their study dated March 1975. The area required for the water treatment plant is approximately 30 acres. Major facilities include:

- Eight rapid mix tanks, each with 1600 cu. ft. capacity, 20' x 8' x 12' high.
- Sixteen flocculation basins each with 50,000 cu. ft. capacity, 100' x 50' x 12' high.
- Thirty sedimentation basins, each 150' x 75' x 15' high.
- Fourteen dual media filters, each with four cells and 676 sq. ft. per cell.
- Fourteen GAC filters, each with four cells and 676 sq. ft. per cell.
- Air-water backwash facilities for filters.
- Nine gravity thickeners, each 100 feet in diameter by 12 feet high.
- Two basket centrifuges, total capacity of 500,000 gallons per day.
- Centrifuge building, 7200 sq. ft.
- Administration, laboratory and maintenance building, 13,000 sq. ft.
- A 1 MG capacity, below ground clearwell and washwater storage basin, 200' x 67' x 12'.
- Chemical feed systems for chlorine, lime, alum, polymer, ammonia, and fluoride.
- Unthickened sludge pumps; 1390 gpm.
- Thickened sludge pumps; 277 gpm.

- Washwater recycle pumps, vertical turbine; 18.2 MGD capacity, 30 foot of head.

- Piping from pump house to rapid mix basins; 530 feet of nine foot diameter prestressed concrete pipe.

- Piping from clearwell to tunnel shaft; 125 feet of nine foot diameter prestressed concrete pipe.

III. Cost Estimates. Order-of-magnitude capital and operating and maintenance cost estimates were developed for the Merrimack River Alternative. Costs are presented in Table 8.12-3. The estimated accuracy of the order-of-magnitude cost estimates is ± 30 percent. All costs are on a July 1982 basis.

- Capital Costs. Capital costs include construction costs; contingency; contractor's overhead and profit; engineering and construction management fees; land acquisition and right-of-way costs; legal, fiscal, and administrative fees; and interest during construction. The total capital cost is estimated to be $493,930,000 for the Merrimack River Alternative. Approximately 60 percent of this cost is for the tunnels and shafts. Approximately 35 percent is for the water treatment plant and sludge disposal landfill.

If the alternative is constructed in three stages as suggested earlier, the following capital costs would be anticipated in the indicated years (expressed in July 1982 dollars):

Date of Completed Construction	System Capacity	Capital Cost (July 1982 $)
1990	165 MGD	$461,300,000
2006	200 MGD	$ 22,400,000
2013	235 MGD	$ 17,400,000
	Total	$501,100,000

Land values in this part of Massachusetts range from $10,000 to $40,000 per acre. Costs have been included for the acquisition of 253 acres of land for the alternative. This area is comprised of approximately 35 acres for the intake structure and water treatment plant site, 2 acres for access to shafts, 66 acres for the spoil piles and 150 acres for the sludge disposal landfill. Capital costs for the spoil piles include the costs for revegetation of the piles after construction is complete.

TABLE 8.12-3: COSTS FOR THE MERRIMACK RIVER ALTERNATIVE

CAPITAL COSTS	
Merrimack River Intake	$ 4,500,000
Water Treatment Plant and Landfill	115,800,000
Tunnels	174,250,000
Shafts	15,420,000
Spoil Piles and Contractors Work Areas	1,680,000
Pumping Facility at Spot Pond	14,170,000
Connection to MDC Shaft 9A	150,000
Dewatering	500,000
Pipeline and Connection to Spot Pond	400,000
48" Distribution Pipeline	8,100,000
Connection to Fells Reservoir	300,000
Total Construction Cost, including Contractor's Overhead and Profit (18)	$ 335,270,000
Contingency	$ 50,290,000
Engineering and Construction Management Fees(03)	38,560,000
Land and Right-of-Way Costs (18)	4,310,000
Legal, Fiscal and Administrative Fees (03)	1,070,000
Interest During Construction (19)	64,430,000
TOTAL CAPITAL COST	$ 493,930,000
ANNUAL OPERATING AND MAINTENANCE COSTS	
Energy Cost (08)	$ 5,490,000
Labor Cost (01)	2,419,000
Materials Cost (12)	1,040,000
Chemical Cost (07)	3,300,000
Waste Disposal Cost (08)	450,000
Replacement Cost (12)	1,900,000
TOTAL ANNUAL O&M COST	$ 14,599,000
ANNUAL COST AND UNIT COST OF WATER	
First Year Amortized Capital and O&M Cost	$ 43,085,000
Unit Cost of Water for First Year of Operation	$ 1,967/MG
Net Present Value/Actual Water Yield	$ 567/MG

Notes:
1. The estimated accuracy of these cost estimates is ±30 percent.
2. Numbers in parentheses, e.g. (18), refer to the Commonwealth of Massachusetts, Subsidiary Accounts and Expenditure Codes for Budgetary Control.
3. Capital costs are presented for the complete construction of the full alternative, with a transfer capacity of 235 MGD.
4. Operating and maintenance costs assume 186 days per year of operation at full capacity of 235 MGD. However, operating and maintenance costs will vary by year depending on constructed capacity of system and demand on system.
5. These costs exclude costs associated with hydropower impacts (see Section 8.14).
6. All costs are expressed in July 1982 dollars.

The capital cost included for the sludge disposal landfill covers the cost of initial development of a solid waste landfill for the codisposal of treatment plant sludge and municipal solid waste. It is assumed that the landfill would be operated by a private waste management company.

Facilities on MDC-owned land are assumed to have no land taking cost and are not included in the above land requirements.

Right-of-way costs were calculated using a rate equal to 50 percent and 25 percent of the cost of purchasing the land for permanent and temporary easements, respectively. Temporary easements would be required for all areas which would be used during the construction period (construction access roads and contractor work areas). It is anticipated that in no areas would permanent easements be required. Temporary and permanent easement and land acquisition requirements are shown in Table 8.12-4.

- Operation, Maintenance and Replacement Costs.

Operating and maintenance costs include costs of energy, labor and consumable items (including materials and chemicals) required to operate and maintain the facilities. The total annual operating and maintenance cost of this Alternative is estimated to be $14,599,000 per year. Approximately 40 percent of this cost is for energy required by the pumping and treatment facilities.

In calculating the unit cost of water (reported elsewhere in this study), an annual allowance was included for replacement of equipment and facilities over the forty year study period. This allowance (which could be considered as a sinking fund for replacement and major repairs) has been estimated to be $1,900,000 per year if the full alternative is constructed all at once. If the alternative is constructed in the three stages described earlier, the estimated allowance for replacement (in July 1982 dollars) is as follows:

Years	Annual Amount
1990 - 2005	$1,600,000
2006 - 2012	$1,800,000
2013 - 2020	$2,000,000

TABLE 8.12-4: LAND ACQUISITION AND EASEMENT REQUIREMENTS
(MERRIMACK RIVER ALTERNATIVE)

LOCATION	LAND ACQUISITION (ACRES)	PERMANENT[2] EASEMENT (ACRES)	TEMPORARY[3] EASEMENT (ACRES)
Intake Structure, Water Treatment Plant Site and Shaft A Area	35	0	4.0
Shaft B	0.5	0	2.0
Shaft C	0.5	0	4.0
Shaft D	0.5	0	2.0
Shaft E	0.5	0	4.0
Shaft F & G, Spot Pond Pump Station Facilities and Pipeline to Low Service Distribution System	0	0	0
Shaft H and Facilities at Fells Res.	0	0	0
Shaft J	0	0	1
Spoil Pile @ Shaft A[1]	0	0	0
Spoil Pile @ Shaft B	2.5	0	0
Spoil Pile @ Shaft C	35.0	0	0
Spoil Pile @ Shaft D	2.5	0	0
Spoil Pile @ Shaft E	26.0	0	0
Sludge Disposal Landfill	150.0	0	0
Total	253.0	0	17.0

Notes. 1. Area included with space requirements for water treatment plant area.
2. Permanent easements are for permanent access roads where not on MDC-owned land. No cost has been assumed for subsurface easements for tunnels.
3. Temporary easements have been assumed for areas required only during construction of the facilities.

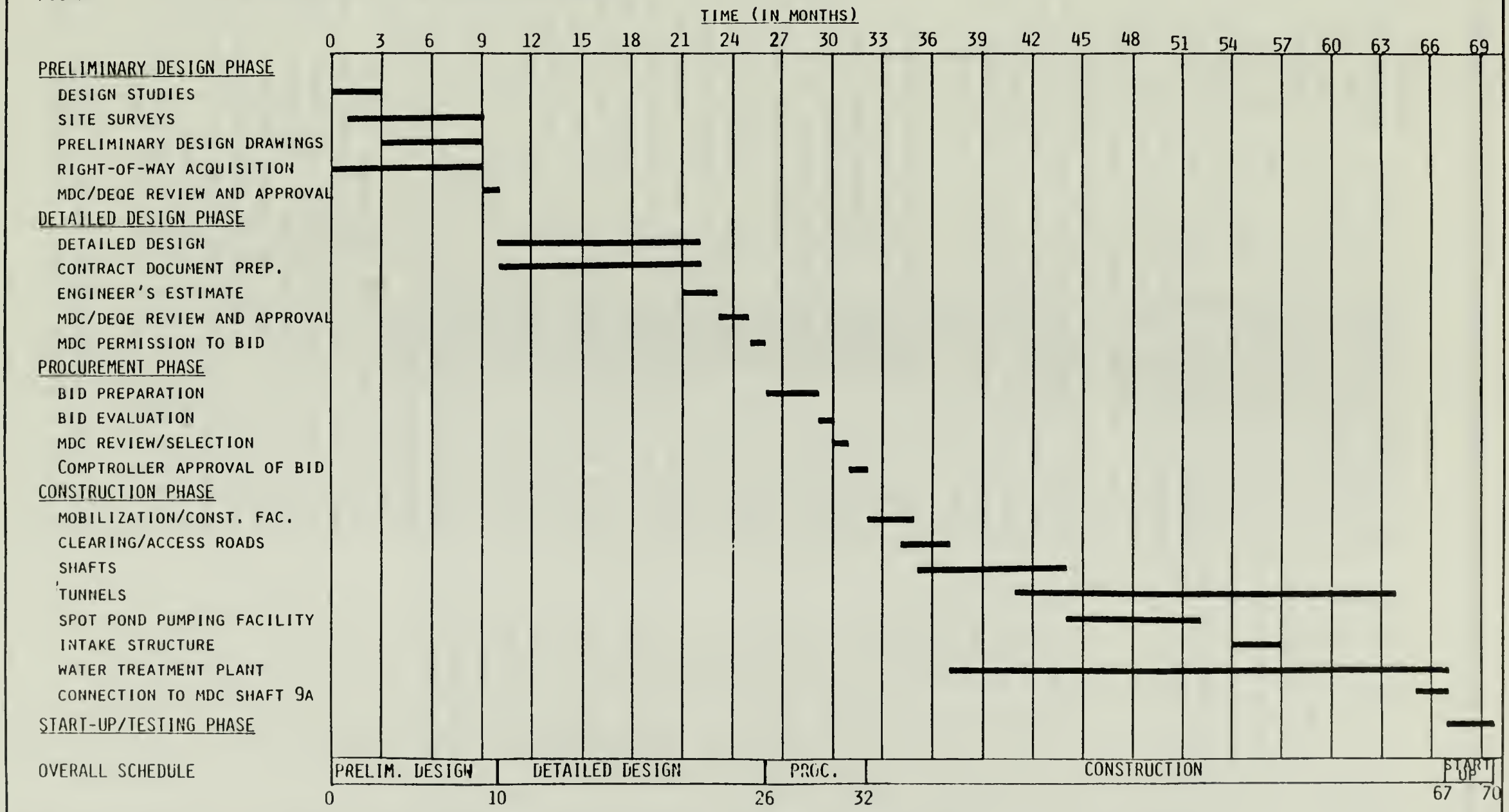
- Construction Scheduling Considerations. Design, procurement and construction of the facilities required for the Merrimack River Alternative will take several years, even after completion of this Environmental Impact Report process. Figure 8.12-2 presents a preliminary schedule for design, procurement, construction and startup of the facilities required for this alternative. The overall duration is 70 months (5 years and 10 months). The design phase would require 26 months; the procurement phase would require 6 months; the construction phase would require 35 months; and the startup phase would require 3 months. The longest single activity on the schedule is the construction of the water treatment plant which is estimated to take 30 months.

IV. Noncost Considerations. Numerous considerations will go into the selection of the preferred alternative for augmenting the MDC water supply. Some of the more obvious considerations are: the yield of the alternative, the cost of water supplied by the alternative, and the anticipated impacts of the alternative. However, there are other important factors which need to be taken into consideration. Two of those factors are reliability and flexibility of the supply alternative.

- Reliability. In this case, reliability is defined as the ability of the water supply alternative to provide a dependable supply of water to the MDC system. In assessing the reliability of a water supply alternative, three components need to be addressed - the reliability of the source of supply, the reliability of the water transmission facilities between the supply and the existing MDC water system, and the susceptibility of loss due to contamination.

  In general, groundwater sources can be considered more reliable sources of water than the surface water sources. Groundwater supplies draw from underground reserves of water on a somewhat continuous basis. Surface water supplies draw from natural streamflow, during periods when the streamflow is high enough to allow diversion. The quantity of water being supplied by surface water sources is highly dependent on the magnitude and duration of high flows in the rivers being considered for diversion and the ability of the reservoirs to store these excess flows; whereas the availability of water from a groundwater source is dependent on the characteristics of the aquifer (e.g. transmissibility, storage capacity and recharge).

FIGURE 8.12-2: DESIGN, PROCUREMENT AND CONSTRUCTION SCHEDULE



NOTE: APPROXIMATELY 6-8 MONTHS ARE REQUIRED BEFORE THE PRELIMINARY DESIGN PHASE FOR PROCUREMENT OF A DESIGN CONSULTANT

The reliability of the yield of the Merrimack River Alternative is highly dependent on the magnitude of the streamflow in the Merrimack River, the frequency of high streamflow conditions and the timing of high streamflows with respect to full reservoir conditions at Quabbin and Wachusett. These factors are especially important considering the operational difficulties and two day time lag associated with starting the flow of water from this system to the MDC transmission and distribution system. The system startup must be closely monitored and controlled to prevent the development of transient pressures in the system and overflow of the MDC reservoirs. Dams on the Merrimack River at Manchester, N.H. and Lowell, Mass. may increase the reliability of this source to a certain degree. These facilities would only be expected to equalize the flow over short periods of time, however, and not over long drought periods.

While the supply element of this alternative can be considered somewhat less reliable than that for groundwater supplies, the withdrawal and transmission elements can be considered somewhat more reliable. Although this alternative depends to a large extent on the use of mechanical equipment and energy for pumping and treating water, there is a high degree of reliability in the system. The water would be introduced into the system through intake screens located in the Merrimack River. Water would be diverted through the intake screens and header pipes to the intake pumps. Only blockage of the screens would prevent or severely limit the diversion. Blockage is controlled by frequent backwashing of the intake screens. As a result, the intake system can be considered very reliable. Spare pumps have been provided in the water treatment plant, intake pumping and Spot Pond pumping to increase reliability. The intake pumping station includes three pumps plus one spare pump, each capable of transferring water at a rate of 54,400 gpm. The Spot Pond pumping station includes five 33,900 gpm pumps and one 28,000 gpm pump. One of the 33,900 gpm pumps has been provided as a spare. The reliability of these pumps is very high. Only under extreme circumstances, such as power failure or facility shutdown, would no pumps be available for transferring and treating water. Likewise, the remaining elements of the transfer system (tunnels and shafts) have a very high reliability. Water flows from the water treatment plant to the Spot Pond Pumping Facility by gravity.

Chemical contamination poses a threat to water supply sources. In the case of groundwater supplies,

contamination can have long-term repercussions. While chemical contamination is a problem for both surface water and groundwater sources, it normally can be more easily and rapidly eliminated from surface water sources than from groundwater sources. Decontamination of groundwater supplies requires extensive measures, usually including isolation of the source of contamination and pumping of the contaminated portion of the groundwater supply to waste or treatment to remove all contamination from the supply.

In the northeastern United States, numerous groundwater supplies have been lost to chemical contamination in recent years. Examples within the MDC service area include the White Lodge Well Supply in Dedham and the Ellis Avenue Well Supply in Norwood. Most commonly, the sources lost to contamination are located in highly developed and urbanized areas. Some potential sources of contamination are: illegal industrial discharges, uncontrolled leachate from landfills, and pollutant laden infiltration from farm or park areas which have been treated with fertilizers or pesticides. A water treatment plant is provided to treat water that is transferred from the Merrimack River. The treatment plant may be capable of treating further contamination if it should occur.

- Flexibility. In this case, flexibility is defined as the capability of responding or conforming to changing or new conditions. As mentioned above, groundwater supplies draw from underground reserves of water. On a long-term, these underground reserves tend to respond to the long-term amount of water withdrawn, as opposed to the rate and frequency of the withdrawal (within reason). The Merrimack River Alternative does not provide storage of excess flows. Therefore, the flexibility of this source from a storage standpoint would be limited.

8.13 ENERGY CONSIDERATIONS

The annual energy cost constitutes a significant portion of the total annual operating and maintenance cost for this alternative. Table 8.12-3 shows the annual energy costs and the total annual operating and maintenance costs for this alternative. The annual energy cost amounts to approximately 40 percent of the total annual operating and maintenance cost. Because the energy costs constitute approximately 40 percent of the total operating and maintenance costs, the total operating and maintenance cost will be very sensitive to a change in the cost of energy. For example, if the cost of energy doubles, the total operating and maintenance costs would increase by 40 percent. This assumes that all other components of the total operating and maintenance cost (i.e. labor, materials and chemicals) remain the same.

While energy costs can fluctuate quite significantly, depending on the price of nuclear, oil and coal fuels; in general, current projections are that energy costs will increase with time at a rate commensurate with the rate of increase in the other components of the total operating and maintenance costs. If so, then the relative proportion between energy cost and the other components of operating and maintenance cost would remain the same. Only if the cost of energy did not increase at the same rate as the other components of operating and maintenance costs would a sensitivity of the operating and maintenance cost to the change in energy cost be noticed.

One cause for a change in the cost of energy might be a change in the mix of electric generating plants. Electricity is generated by fossil-fuel power plants, nuclear power plants, and hydroelectric power plants in Massachusetts. Generally, it is more costly to generate electricity at fossil-fuel (oil, coal, etc.) power plants than it is from either nuclear or hydroelectric power plants. Therefore, as the mix in fuel sources changes, so might the cost of energy.

Future energy considerations in Massachusetts include load management to minimize peak demands, conversion of oil-fired plants to coal, and possible purchase of hydroelectric power from Canada. Each of these factors should help to dampen increases in power costs resulting from a greatly increased cost of oil, coal and nuclear fuel should this occur.

Therefore, while energy costs do constitute a significant portion of the total operating and maintenance costs, it is believed that energy costs will increase generally at the same rate as the other components of the total operating and maintenance costs.

8.14 POTENTIAL IMPACTS ON HYDROPOWER PRODUCTION

Introduction

The purpose of this section is to assess the impact of the Merrimack River Alternative on hydropower production. The hydropower facilities affected are the MDC hydropower plants and hydropower facilities on the Merrimack River. These facilities are discussed below.

MDC Hydropower Facilities

Presently the MDC has four hydroplants within its transmission and distribution system (See Figure 8.14-1, Existing MDC Hydropower Plants); three of these are currently in operation. The three operating plants are located at the Winsor Dam (Winsor Dam Plant), the Quabbin Aqueduct discharge to the Wachusett Reservoir (Oakdale Plant), and the Wachusett Reservoir Intake leading to the Wachusett-Marlborough Tunnel (Cosgrove Plant). The fourth plant, which is located at the Wachusett Dam, is not currently utilized. A fifth hydropower plant is presently under consideration and would be located on the transfer line between the Hultman and Weston Aqueducts near MDC Shaft 4 in South Borough, Massachusetts.

Winsor Dam Plant - The Winsor Dam hydroplant consists of one 1200 kW generator powered by two Francis turbine operating at 145 feet of head. This plant, which is powered by flow released from the Quabbin Reservoir, is located at the Winsor Dam outlet to the Swift River. A minimum release of 20 MGD (31 cfs) is required for the months of December through May. A minimum release of 71 MGD (110 cfs) is required for the months of June through November during low flow conditions in the Connecticut River. Discharges to the Swift River seldom exceed minimum release requirements due to the demand on the reservoir for water supply. However, to operate the turbines at maximum efficiency, a discharge rate of 110 cfs is maintained until the minimum daily flow is reached. Discharge is then discontinued until the next day.

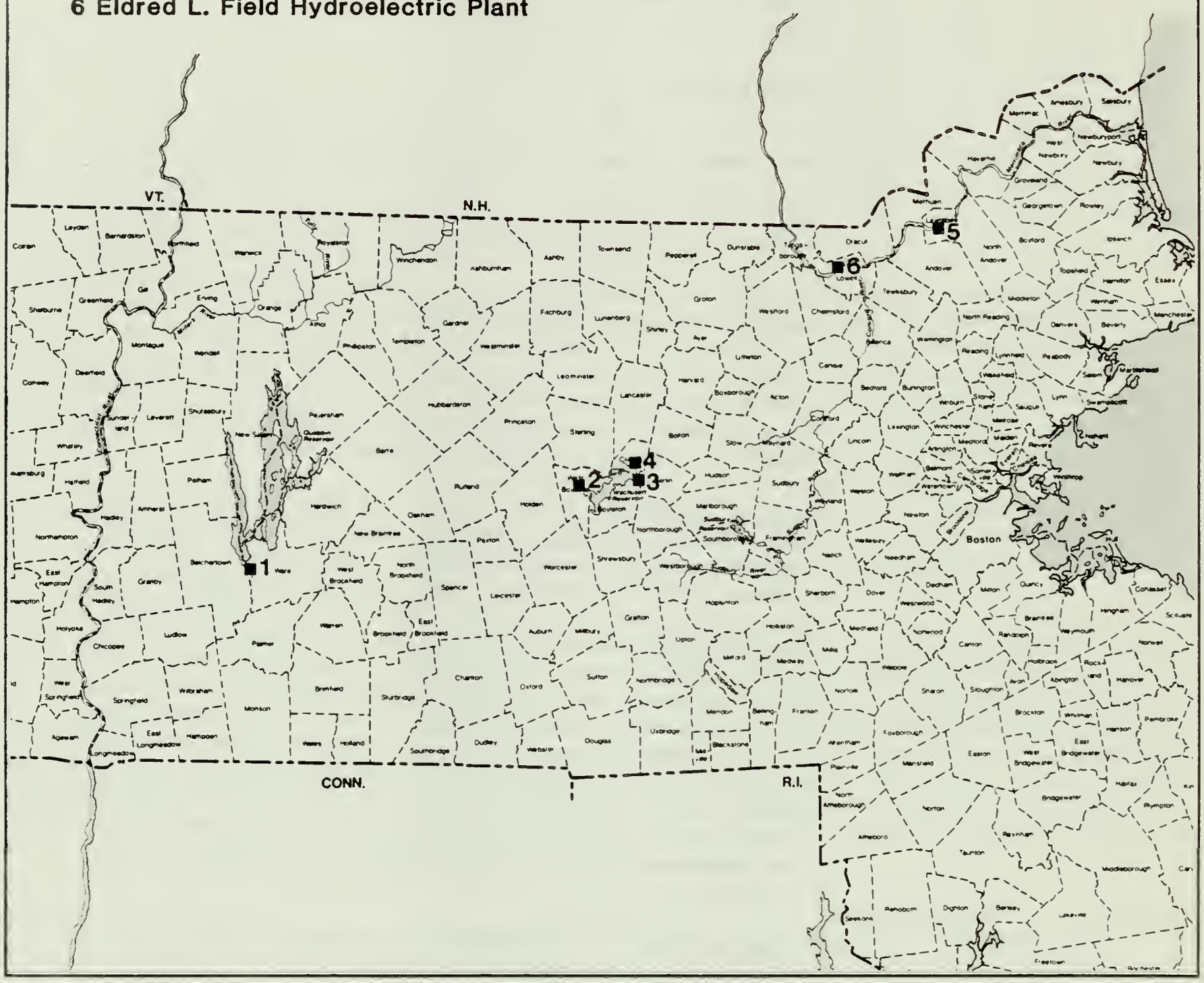
Oakdale Plant - The Oakdale hydroplant consists of one 3500 kW generator powered by a Francis turbine operating at approximately 115 feet of head. This plant, which is powered by the flow from the Quabbin Reservoir, is located at the outlet of the Quabbin Aqueduct. Electrical production is approximately 70 MWH per day when operating. The operating period, which is dependent on yearly flow requirements, currently averages approximately 200 days per year.

MDC Plants

1 Winsor Dam Plant
2 Oakdale Plant
3 Cosgrove Plant
4 Wachusett Dam Plant

Merrimack River Plants

5 Lawrence Hydroelectric Plant
6 Eldred L. Field Hydroelectric Plant

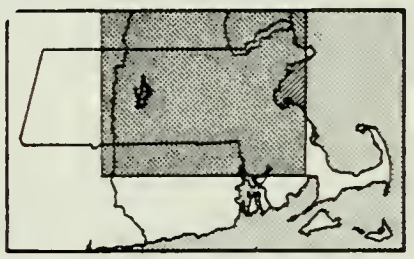


Legend

■1 Location of hydropower facilities. See key above for name of each plant.

Figure 8.14-1.
Hydropower Plants

0 5 10 20 miles



Cosgrove Plant - The Cosgrove hydroplant consists of two 1680 kW generators powered by two Kaplan turbine operating at 80 feet of head. This plant is located at the Wachusett/Marlborough Tunnel intake. All water delivered from Quabbin and Wachusett Reservoirs to the Boston Metropolitan Area must pass through this plant. The flow from Wachusett Reservoir is currently, essentially continuous at approximately 270 to 300 MGD. Electricity production is approximately 46 MWH per day.

Wachusett Dam Plant - The Wachusett Dam hydroplant consists of four 1000 kW generators powered by four Francis turbines. These units which are located on the Wachusett Aqueduct to Sudbury Reservoir are not currently operated since the Wachusett Aqueduct is no longer used. A 1976 study (Vanderweil, 1976) reported that these units were still in excellent condition and the MDC has considered bringing them back on line for power production purposes. However, since the plant is not operating, no assessment of potential impacts will be made.

Weston/Hultman Aqueduct Plant - The proposed Weston/Hultman Aqueduct hydroplant would make use of the head difference between the Hultman Aqueduct and Weston Aqueduct flow transfer to generate power. This plant will generate the same amount of electricity with and without this alternative. Therefore, there will be no impact on hydropower production at this plant.

Merrimack River Hydropower Facilities

The Merrimack River Alternative would divert water from the Merrimack River at Tyngsboro, Massachusetts. As a result, downstream hydropower facilities may be impacted depending on their flow capacity for hydropower production and the resultant flow in the Merrimack River after the diversion. There are numerous hydropower plants in Lowell and Lawrence, however, two facilities account for the majority of the water used for hydropower production. They are the Eldred L. Field Hydroelectric (Boott Mills) plant in Lowell and the Lawrence Hydroelectric Facility in Lawrence. For this analysis, it will be assumed that only these plants are impacted by a reduction in flow in the river below the plant operating capacity. A brief description of these facilities follows.

Eldred L. Field Hydroelectric Facility - This plant, which is located at the Pawtucket Dam in Lowell, Massachusetts, is currently under construction and is expected to become operational in the latter part of 1985. The hydroplant will consist of two 7500 kW generator powered by two full Kaplan turbines operating at approximately 35 feet of head. Net annual electrical production is expected to be

approximately 85 million kWhr/yr. The plant will be operated by Boott Hydropower, Inc.

Lawrence Hydroelectric Facility - The Lawrence Hydroelectric facility is located at the Great Stone Dam in Lawrence, Massachusetts. The hydroplant consists of two 8,500 kW generators powered by two Kaplan Bulb turbines operating at approximately 30 feet of head. Net annual electric production is reported to be approximately 70 million kWhr/yr. The plant is owned and operated by Lawrence Hydroelectric Associates.

Assessment of Impacts on Hydropower Production

Methodology

In the design of the Merrimack River Alternative it was assumed that the water treatment plant would be built in three stages. These stages would be 165 MGD, 200 MGD and 235 MGD of treatment capacity. Safe yield model runs were obtained for the Merrimack River Alternative operating at each of these three rates. In addition, the model was run for a condition where there was no diversion of water. Using the fifty year monthly average data from the safe yield model, an estimate of hydropower generation for each of the plants was estimated. The difference in hydropower generation for the condition with the alternative operating at one of the three flow rates and with alternative not operating would represent the impact on hydropower production. Specific assumptions used in estimating the impact to hydropower production for each of the three diversion rates versus the case of no diversion are discussed below.

Winsor Dam Plant - In determining the impact to hydropower production the following assumptions were made for the Winsor Dam Plant: overall plant efficiency of 77 percent, tailwater elevation of 385 ft. (Boston City Base); energy rate of 0.027 $/kWhr; and a maximum flow capacity of 71 MGD. The energy rate is based on the average of rates reported for 1982 through 1985 expressed in 1982 dollars. For a 165 MGD treatment plant capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin Reservoir at Winsor Dam would be less. The net effect is an average annual decrease in hydropower production of 488,000 kWhr/yr was indicated. At the above energy rate this resulted in an decrease in revenues of $13,000 per year (1982 dollars). For a 200 MGD treatment plant capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin Reservoir at Winsor Dam would be less. The net effect is hydropower production decreased by 585,000 kWh/yr and revenues decreased by $16,000 per year (1982 dollars). For a 235 MGD treatment plant

capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin Reservoir at Winsor Dam would be less. The net effect is hydropower production decreased by 768,000 kWhr/yr and revenues decreased by $21,000 per year (1982 dollars).

Oakdale Plant - In determining the impact to hydropower production, the following assumptions were made for the Oakdale Plant: overall plant efficiency of 70 percent; energy rate of 0.027 $/kWhr; and a maximum flow capacity of 325 MGD. The energy rate is based on the average of rates reported for 1982 through 1985, expressed in 1982 dollars. The tailwater elevation is approximately El. 395 ft. (Boston City Base). MDC reports that in order to be able to transfer more than 325-330 MGD of water from Quabbin Reservoir to Wachusett Reservoir, the Oakdale hydroplant must be totally bypassed. Therefore, it was assumed that when transferring more than 325 MGD from Quabbin to Wachusett Reservoirs, the hydroplant must be bypassed and no power would be produced. As a result, about 26, 27 and 29 percent of the time for 165, 200 and 235 MGD water treatment plant capacity respectively, the flow transferred would not be used for hydropower production. For a 165 MGD treatment plant capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin to Wachusett would be greater. However, during about 26 percent of the time the hydroplant would be bypassed. The net effect is an average annual decrease in hydropower production of 7,230,000 kWhr/yr. At the above energy rate, this resulted in an decrease in revenues of $195,000 per year (1982 dollars). For a 200 MGD treatment plant capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin to Wachusett would be greater. However, during about 27 percent of the time the hydroplant would be bypassed. The net effect is hydropower production decreased by 7,830,000 kWhr/yr and revenues decreased by $210,000 per year (1982 dollars). For a 235 MGD treatment plant capacity, on average, Quabbin Reservoir elevations would be lower and flows from Quabbin to Wachusett would be greater. However, during about 29 percent of the time the hydroplant would be bypassed. The net effect is hydropower production decreased by 8,840,000 kWhr/yr and revenues decreased by $240,000 per year (1982 dollars).

Cosgrove Plant - In determining the impact to hydropower production the following assumptions were made for the Cosgrove Hydroplant: overall plant efficiency of 75 percent; and tailwater elevation of 316 ft. (Boston City Base). The power produced is sold equally to two local utilities. The energy rate used was 0.0295 $/kWhr. This is based on the average of rates reported for 1982 through 1985, expressed in 1982 dollars, for the two utilities. For a 165 MGD treatment plant capacity, on average,

Wachusett Reservoir elevations would be slightly higher and the flow from Wachusett Reservoir would be slightly increased. The net effect is an average annual increase in hydropower production of 305,000 kWhr/yr. At the above energy rate this resulted in an increase in revenues of $9,000 per year (1982 dollars). For a 200 MGD treatment plant capacity, on average, Wachusett Reservoir elevations would be slightly higher and the flow from Wachusett Reservoir would be slightly increased. The net effect is hydropower production increased by 294,000 kWhr/yr and revenues increased by $8,700 per year (1982 dollars). For a 235 MGD treatment plant capacity, on average, Wachusett Reservoir elevations would be slightly higher and the flow from Wachusett Reservoir would be slightly increased. The net effect is hydropower production increased by 268,000 kWhr/yr and revenues increased by $7,900 per year (1982 dollars).

Eldred L. Field Hydroelectric Plant - In determining the impact to hydropower production the following assumptions were made for this Plant: overall plant efficiency of 85 percent; head difference available for power production of 35 feet; energy rate of 0.081 $/kWhr; and a maximum flow capacity of 7100 MGD. Any flow above the assumed maximum of 7100 MGD would be spillage with no resultant power production. The energy rate is based on the reported 1984 rates deescalated two years at 5.5% to obtain the 1982 adjusted rate. For a 165 MGD treatment plant capacity, an average annual decrease in hydropower production of 2,050,000 kWhr/yr was indicated. At the above energy rate this resulted in an decrease in revenues of $170,000/yr. For a 200 MGD treatment plant capacity, hydropower production decreased by 2,500,000 kWhr/yr and revenues decreased by $200,000/yr. For a 235 MGD treatment plant capacity, hydropower production decreased by 2,930,000 kWhr/yr and revenues decreased by $240,000/yr.

Lawrence Hydroelectric Facility - In determining the impact to hydropower production the following assumptions were made for this plant: overall plant efficiency of 85 percent; head difference available for power production of 35 feet; energy rate of 0.072 $/kWhr; and a maximum flow capacity of 7800 MGD. Any flow above the assumed maximum of 7,800 MGD would be spillage with no resultant power production. The energy rate is based on the reported 1984 rates deescalated two years at 5.5% to obtain the 1982 adjusted rate. For a 165 MGD treatment plant capacity an average annual decrease in hydropower production of 1,760,000 kWhr/yr was indicated. At the above energy rate this resulted in an decrease in revenues of $130,000/yr. For a 200 MGD treatment plant capacity, hydropower production decreased by 2,140,000 kWhr/yr and revenues decreased by $150,000/yr. For a 235 MGD treatment plant

capacity, hydropower production decreased by 2,510,000 kWhr/yr and revenues decreased by $180,000/yr.

Summary of Impacts

Tables 8.14-1, 8.14-2, and 8.14-3 present the estimated impacts to hydropower for the Merrimack River Diversion operating at 165 MGD, 200 MGD and 235 MGD respectively. From these tables it is indicated that an overall negative impact on hydropower production is expected from the Merrimack River Alternative. For the condition where the Merrimack River Alternative operates at 165 MGD which is anticipated to occur in year 2005, a loss in revenues of approximately $200,000/yr (1982 dollars) is expected. For the alternative operating at 200 MGD which is anticipated to occur in year 2013, a loss in revenues of approximately $219,000/yr (1982 dollars) is expected. For the alternative operating at 235 MGD which is anticipated to occur in year 2020, a loss in revenues of approximately $252,000/yr (1982 dollars) is expected.

TABLE 8.14-1 MERRIMACK RIVER ALTERNATIVE - OPERATION AT 165 MGD

Impact to Hydropower Generation

Hydroplant	Oct (kWh/mo)	Nov (kWh/mo)	Dec (kWh/mo)	Jan (kWh/mo)	Feb (kWh/mo)	Mar (kWh/mo)	Apr (kWh/mo)	May (kWh/mo)	Jun (kWh/mo)	Jul (kWh/mo)	Aug (kWh/mo)	Sep (kWh/mo)	Annual (kWh/yr
Winsor Dam Plant	(51,153)	(49,089)	(59,677)	(71,801)	8,102	(143,671)	(5,160)	(42,318)	(5,550)	(49,425)	(8,733)	(9,291)	(487,68
Oakdale Hydroplant	(718,948)	(118,285)	(371,013)	(382,416)	(346,777)	(129,567)	(65,525)	(423,960)	(745,470)	(1,028,217)	(1,590,355)	(1,314,036)	(7,234,56
Cosgrove Hydroplant	468,223	(74,129)	(332,312)	(328,487)	(287,016)	(186,974)	(272,189)	(202,810)	97,222	514,415	471,883	429,954	384,65
subtotal	(389,878)	(241,423)	(763,003)	(774,619)	(625,690)	(454,211)	(342,875)	(668,288)	(653,798)	(563,227)	(1,127,205)	(893,372)	(7,417,58
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(273,771)	(423,896)	(421,951)	(378,287)	0	0	(340,556)	(201,460)	0	0	(10,475)	(2,050,39
Lawrence Hydro Facility	0	(234,661)	(363,364)	(361,673)	(324,268)	0	0	(291,985)	(172,680)	0	0	(8,978)	(1,757,52
NET IMPACT	(389,878)	(749,855)	(1,550,262)	(1,558,243)	(1,328,245)	(454,211)	(342,875)	(1,300,749)	(1,027,939)	(563,227)	(1,127,205)	(912,825)	(11,225,51

Impact to Hydropower Revenues

Hydroplant	Oct ($/mo)	Nov ($/mo)	Dec ($/mo)	Jan ($/mo)	Feb ($/mo)	Mar ($/mo)	Apr ($/mo)	May ($/mo)	Jun ($/mo)	Jul ($/mo)	Aug ($/mo)	Sep ($/mo)	Annual ($/yr)
Winsor Dam Plant	(1,381)	(1,323)	(1,611)	(1,939)	219	(3,879)	(139)	(1,143)	(150)	(1,334)	(236)	(251)	(13,16
Oakdale Hydroplant	(19,412)	(3,194)	(10,017)	(10,325)	(9,363)	(3,498)	(1,769)	(11,447)	(20,128)	(27,762)	(42,940)	(35,479)	(195,33
Cosgrove Hydroplant	13,577	(2,187)	(9,803)	(9,452)	(8,467)	(5,339)	(8,030)	(5,959)	2,868	15,175	13,921	12,684	8,98
subtotal	(7,216)	(6,704)	(21,432)	(21,716)	(17,611)	(12,716)	(9,938)	(18,549)	(17,409)	(13,921)	(29,255)	(23,046)	(199,51
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(22,175)	(34,336)	(34,178)	(30,641)	0	0	(27,585)	(16,318)	0	0	(848)	(166,06
Lawrence Hydro Facility	0	(16,896)	(26,162)	(26,040)	(23,347)	0	0	(21,017)	(12,433)	0	0	(646)	(126,54
NET IMPACT	(7,216)	(45,775)	(81,930)	(81,934)	(71,680)	(12,716)	(9,938)	(67,151)	(46,161)	(13,921)	(29,255)	(24,541)	(492,13

TABLE 8.14-2 MERRIMACK RIVER ALTERNATIVE - OPERATION AT 200 MGD

Impact to Hydropower Generation

Hydroplant	Oct (kWh/mo)	Nov (kWh/mo)	Dec (kWh/mo)	Jan (kWh/mo)	Feb (kWh/mo)	Mar (kWh/mo)	Apr (kWh/mo)	May (kWh/mo)	Jun (kWh/mo)	Jul (kWh/mo)	Aug (kWh/mo)	Sep (kWh/mo)	Annual (kWh/yr)
Winsor Dam Plant	(56,617)	(64,230)	(65,995)	(78,177)	(4,513)	(147,588)	(7,225)	(58,222)	(6,145)	(60,562)	(18,427)	(17,129)	(584,831)
Oakdale Hydroplant	(820,495)	(176,202)	(449,139)	(464,193)	(447,278)	(173,716)	(73,688)	(482,626)	(778,339)	(934,207)	(1,687,327)	(1,346,968)	(7,834,178)
Cosgrove Hydroplant	553,894	(92,252)	(399,362)	(409,063)	(347,357)	(233,064)	(332,974)	(264,927)	95,775	620,847	575,690	526,164	294,271
subtotal	(323,218)	(332,684)	(914,496)	(951,433)	(799,149)	(554,368)	(413,887)	(804,876)	(688,709)	(373,923)	(1,130,064)	(837,932)	(8,124,737)
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(329,205)	(511,733)	(521,628)	(457,021)	0	0	(413,884)	(255,771)	0	(29)	(11,542)	(2,500,814)
Lawrence Hydro Facility	0	(282,176)	(438,653)	(447,110)	(391,755)	0	0	(354,758)	(219,232)	0	(25)	(9,869)	(2,143,578)
NET IMPACT	(323,218)	(944,065)	(1,864,882)	(1,920,171)	(1,647,925)	(554,368)	(413,887)	(1,573,519)	(1,163,712)	(373,923)	(1,130,117)	(859,342)	(12,769,129)

Impact to Hydropower Revenues

Hydroplant	Oct ($/mo)	Nov ($/mo)	Dec ($/mo)	Jan ($/mo)	Feb ($/mo)	Mar ($/mo)	Apr ($/mo)	May ($/mo)	Jun ($/mo)	Jul ($/mo)	Aug ($/mo)	Sep ($/mo)	Annual ($/yr)
Winsor Dam Plant	(1,529)	(1,734)	(1,782)	(2,111)	(122)	(3,985)	(195)	(1,572)	(166)	(1,635)	(498)	(462)	(15,790)
Oakdale Hydroplant	(22,153)	(4,757)	(12,127)	(12,533)	(12,077)	(4,690)	(1,990)	(13,031)	(21,015)	(25,224)	(45,558)	(36,368)	(211,523)
Cosgrove Hydroplant	16,346	(2,721)	(11,781)	(12,067)	(10,247)	(6,875)	(9,823)	(7,789)	2,825	18,315	16,983	15,522	8,681
subtotal	(7,342)	(9,213)	(25,690)	(26,711)	(22,445)	(15,551)	(12,007)	(22,392)	(18,356)	(8,544)	(29,072)	(21,309)	(218,632)
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(26,666)	(41,450)	(42,252)	(37,019)	0	0	(33,525)	(20,717)	0	(2)	(935)	(202,566)
Lawrence Hydro Facility	0	(20,317)	(31,583)	(32,192)	(28,206)	0	0	(25,543)	(15,785)	0	(2)	(711)	(154,338)
NET IMPACT	(7,342)	(56,195)	(98,723)	(101,155)	(87,670)	(15,551)	(12,007)	(81,459)	(54,858)	(8,544)	(29,077)	(22,954)	(575,536)

TABLE 8.14-3 MERRIMACK RIVER ALTERNATIVE - OPERATION AT 235 MGD

Impact to Hydropower Generation

Hydroplant	Oct (kWh/mo)	Nov (kWh/mo)	Dec (kWh/mo)	Jan (kWh/mo)	Feb (kWh/mo)	Mar (kWh/mo)	Apr (kWh/mo)	May (kWh/mo)	Jun (kWh/mo)	Jul (kWh/mo)	Aug (kWh/mo)	Sep (kWh/mo)	Annual (kWh/yr)
Winsor Dam Plant	(61,259)	(65,955)	(74,497)	(68,673)	(40,572)	(171,317)	(9,289)	(163,569)	(6,748)	(59,918)	(20,259)	(25,866)	(767,913)
Oakdale Hydroplant	(943,234)	(361,233)	(512,872)	(594,774)	(513,333)	(185,679)	(88,544)	(514,512)	(826,149)	(1,211,888)	(1,653,470)	(1,436,268)	(8,841,977)
Cosgrove Hydroplant	645,722	(107,275)	(464,159)	(505,460)	(409,877)	(271,696)	(421,145)	(313,168)	96,982	713,667	681,829	622,217	268,443
subtotal	(358,771)	(534,464)	(1,051,528)	(1,168,906)	(962,982)	(628,692)	(518,979)	(991,248)	(735,908)	(557,259)	(991,900)	(839,917)	(9,340,547)
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(383,656)	(598,933)	(619,216)	(530,225)	0	0	(478,217)	(305,223)	0	(116)	(12,581)	(2,928,167)
Lawrence Hydro Facility	0	(328,848)	(513,396)	(530,732)	(454,581)	0	0	(409,981)	(261,644)	0	(75)	(10,783)	(2,509,879)
NET IMPACT	(358,771)	(1,246,968)	(2,163,856)	(2,318,854)	(1,947,789)	(628,692)	(518,979)	(1,879,358)	(1,302,774)	(557,259)	(992,891)	(863,281)	(14,778,594)

Impact to Hydropower Revenues

Hydroplant	Oct ($/mo)	Nov ($/mo)	Dec ($/mo)	Jan ($/mo)	Feb ($/mo)	Mar ($/mo)	Apr ($/mo)	May ($/mo)	Jun ($/mo)	Jul ($/mo)	Aug ($/mo)	Sep ($/mo)	Annual ($/yr)
Winsor Dam Plant	(1,654)	(1,781)	(2,011)	(1,854)	(1,095)	(4,626)	(251)	(4,416)	(182)	(1,618)	(547)	(698)	(20,734)
Oakdale Hydroplant	(25,467)	(9,753)	(13,848)	(16,059)	(13,860)	(5,013)	(2,391)	(13,892)	(22,306)	(32,697)	(44,644)	(38,779)	(238,709)
Cosgrove Hydroplant	19,049	(3,165)	(13,693)	(14,911)	(12,068)	(8,015)	(12,424)	(9,238)	2,861	21,053	20,114	18,355	7,919
subtotal	(8,073)	(14,699)	(29,552)	(32,824)	(27,023)	(17,654)	(15,065)	(27,546)	(19,627)	(13,262)	(25,077)	(21,122)	(251,524)
Other Hydroplants													
Eldred L. Field Hydro Facility	0	(31,076)	(48,514)	(50,157)	(42,948)	0	0	(38,736)	(24,723)	0	(9)	(1,019)	(237,182)
Lawrence Hydro Facility	0	(23,677)	(36,964)	(38,213)	(32,724)	0	0	(29,513)	(18,838)	0	(5)	(776)	(180,711)
NET IMPACT	(8,073)	(69,452)	(115,030)	(121,193)	(102,696)	(17,654)	(15,065)	(95,795)	(63,188)	(13,262)	(25,092)	(22,918)	(669,417)

8.20 WATER QUALITY

8.21 WATER QUALITY OF THE MERRIMACK RIVER

8.21.1 Baseline Conditions

I. Existing Conditions

- Water Quality - Historic water quality data for the Merrimack River were assembled from many sources and analyzed.

- Data Sources and Extent - This section presents data describing the existing water quality of the Merrimack River. A significant amount of water quality data has been generated for the Merrimack River in the past decade. Table 8.21-1 summarizes the historic water quality data available from various agencies and used in this study.

  In addition, the sampling stations associated with each data collection program are listed. No field surveys were conducted to collect additional surface water quality data during the course of this study. The two primary sources available are the monitoring network of the U.S. Geological Survey (USGS) and the Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control (MDWPC). Additional data are also available from the City of Lowell related to monitoring at the City's drinking water intake. The location of sampling points are presented in Figure 8.21-1.

No water quality monitoring station exists in the immediate vicinity of the proposed MDC intake, but the MDWPC maintains two stations just downstream from the intake: MR01, at the Rt. 113 bridge; and MR02, at the Lowell water intake. (See Figure 8.21-1). The USGS also maintains a water quality monitoring station near the Lowell intake. There are major wastewater treatment facilities serving New Hampshire communities upstream, but no known point source of wastewater exists between any of the water quality monitoring stations and the proposed diversion intake location. Thus, the data collected at these stations is considered representative of the water quality conditions in the vicinity of the proposed intake location and was used to document the water quality of the diverted water.

TABLE 8.21-1. SUMMARY OF DATA SOURCES AND EXTENT OF AVAILABLE DATA USED IN BASELINE WATER QUALITY DOCUMENTATION OF THE MERRIMACK RIVER.

COLLECTING AGENCY	EXTENT OF AVAILABLE DATA	SAMPLING STATION
U. S. Geological Survey	Instantaneous measurements (grab samples) of, physical, chemical, biological, and microbiological parameters as well as organics and metals levels on a monthly basis from 1969 to current year.	At intake of Lowell water treatment plant and approximately 3 miles below the proposed diversion point.
Massachusetts Division of Water Pollution Control	Water quality surveys of physical and chemical parameters, and bacterial levels during summer of 1974, 1979 and 1981.	22 Stations: MR01 - At Rt. 113 bridge and above the proposed diversion. MR02 - At Lowell water supply intake and below the proposed diversion. MR03/ MR22 - Below the diversion.

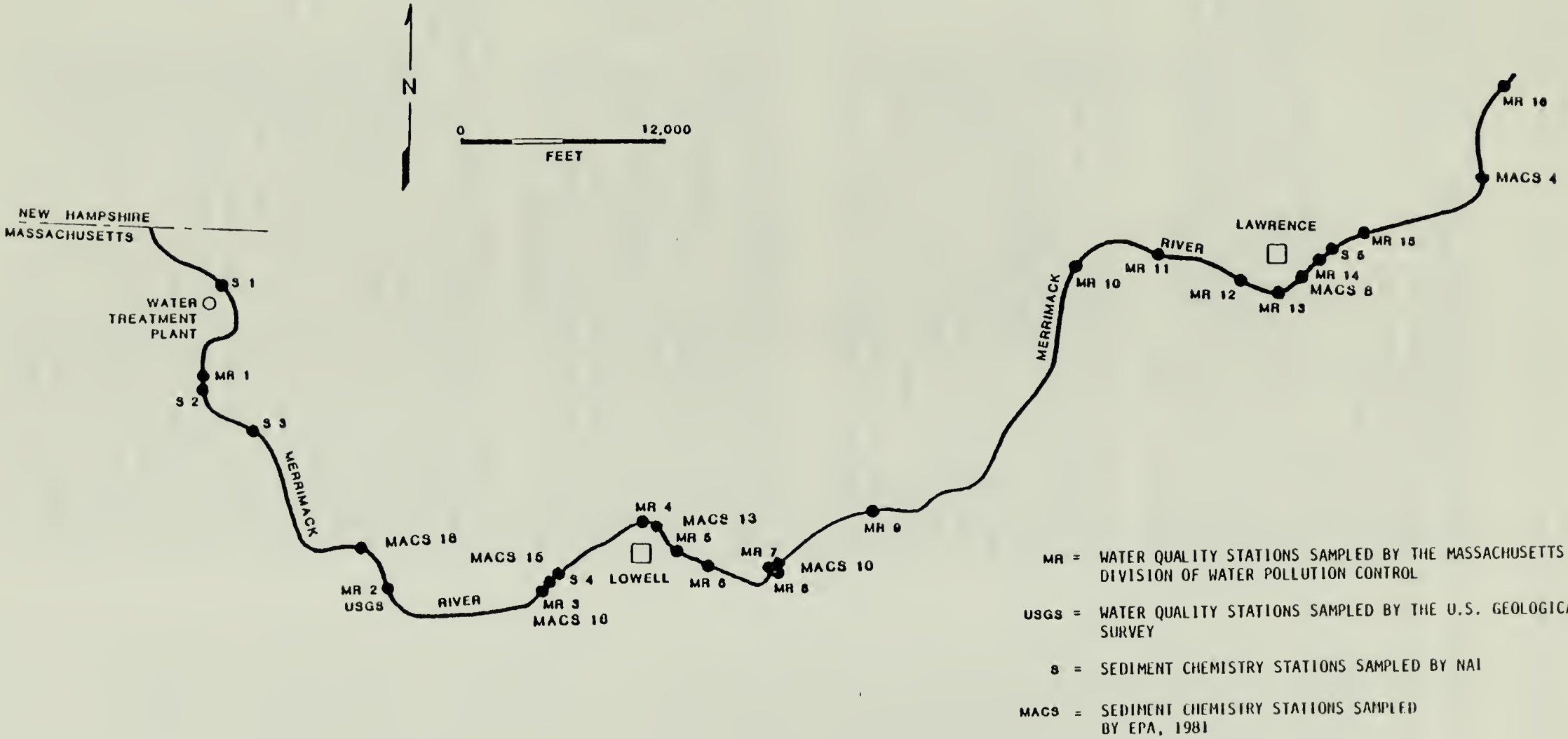


Figure 8.21-1. Water Quality Stations on the Merrimack River sampled by previous investigators and Sediment Chemistry Stations sampled by NAI in 1982.

The data collected at other MDWPC stations downstream from the proposed MDC water intake are used to document the baseline water quality conditions and assess the downstream impacts of diverting water from the Merrimack.

The MDWPC data sets reflect summer samplings only. For those parameters that display distinct seasonal trends (e.g., temperature, dissolved oxygen), only the USGS data set (representing 12 months of sampling) was used to determine the range and mean concentrations reported herein.

- Water Quality Parameters - The water quality parameters included in the evaluation of the baseline water quality of the Merrimack River are presented in Table 8.21-2. They were selected based on public health, aquatic habitat, and aesthetic considerations (New England Research, Inc. 1982). The water quality parameters in Table 8.21-2 are classified into five groups: common indicators, bacteria, nutrients, metals and organics. These are basically the same parameters selected for the Connecticut River. (See Section 5.21.1.I.)

- Water Quality Standards - Both the National Interim Primary Drinking Water regulations and the Massachusetts drinking water regulations have been used to evaluate the water quality of the freshwater portion of the Merrimack River. In general, drinking water regulations of Massachusetts (MDWS, 1977) match the Federal regulations in terms of the contaminants and the associated maximum levels allowed in the drinking waters in the Commonwealth.

  In Massachusetts, general minimum water quality criteria have been developed for all waters in terms of aesthetics, radioactive substances, tainting substances, color, turbidity, total suspended solids, oil and grease, and nutrients (MDWPC, 1979). In addition, specific numerical criteria for dissolved oxygen, temperature, pH, and fecal coliforms are established for various water classifications. These criteria, along with state water use designations form water quality standards for individual streams or portions of streams. The Merrimack River from the mouth to mile point 21.9 (the estuarine portion) is classified as Class SB water and designated for the use of marine fishery, shell-fishing, and recreation. From mile point 21.9 to mile point 49.8, (The Massachusetts-New Hampshire border), the Merrimack River is classified as Class B water suitable for warm water fishing and recreation. The water quality standards for these

TABLE 8.21-2. WATER QUALITY PARAMETERS ANALYZED

PARAMETER	RATIONALE FOR CONSIDERATION* PUBLIC HEALTH	AQUATIC HABITAT	AESTHETICS
Group I - Indicators			
Temperature		x	
Dissolved Oxygen		x	
pH	x	x	x
Alkalinity		x	
BOD_5		x	
COD		x	
Total Dissolved Solids		x	x
Total Suspended Solids		x	x
Chloride	x	x	x
Fluoride	x		x
Sulfate		x	x
Turbidity	x	x	x
Group II - Bacteria, Algae			
Total coliforms	x		
Fecal coliforms	x		
Algae		x	x
Chlorophyll a		x	x
Group III - Nutrients			
Ammonia		x	
Nitrate	x	x	x
Total Phosphorus		x	x
Group IV - Metals			
Arsenic	x		
Barium	x		
Cadmium	x	x	
Chromium	x	x	
Copper	x	x	x
Iron		x	x
Lead	x	x	
Manganese			x
Mercury	x	x	
Nickel		x	
Selenium	x	x	
Silver	x	x	
Sodium	x		
Zinc		x	x

(Continued)

TABLE 8.21-2. (Continued)

PARAMETER	RATIONALE FOR CONSIDERATION* PUBLIC HEALTH	AQUATIC HABITAT	AESTHETICS
Group V - Organics			
Oil and grease		x	x
Phenols	x		
Aldrin/Dieldrin	x	x	
Chlordane	x	x	
DDT	x	x	
Endosulfan	x	x	
Endrin	x	x	
Heptachlor	x	x	
Lindane	x	x	
Methoxychlor	x	x	
Mirex	x	x	
PCB	x	x	
Toxaphene	x	x	
2,4-Dichlorophenoxyacetic acid	x	x	
2,4,5-TP Silvex	x	x	

*New England Research, Inc., 1982a & b.

water classifications and use designations are shown in Table 8-21-3.

- Existing Water Quality - The existing water quality data near the proposed diversion point are presented in Table 8.21-4 with the range and mean given for each parameter. Most constituents are within the concentration range expected for a major river receiving point and nonpoint source discharges. The available water quality data base provides an over- view of water quality and does not indicate excessive levels of contaminants for many parameters.

  Table 8.21-4 also compares the existing water quality with maximum contaminant levels (MCL) allowed in drinking water. For the data sets available, only turbidity and total coliform bacteria levels exceed the allowable limits. Available data show trace metals and trace organics are either present at very low levels or could not be detected by the analytical methods used. These data do not encompass all potential pollutants. Concentration levels of other metals and organics are unknown.

  Further analysis of the USGS data was made to evaluate long-term trends, if any, of the water quality in the Merrimack River. Figure 8.21-2 presents the annual averages and standard deviations for a number of key water quality parameters for which long-term data are available from the USGS station (intake for the Lowell water supply).

  Figure 8.21-2 suggests that there has been a slight improvement in water quality during the past ten years, noticeably for dissolved oxygen, total Kjeldahl nitrogen and nitrate nitrogen. Such an observation is consistent with the recent reports that the water quality in the Merrimack River has improved during the past decade. Other parameters, such as temperature, pH, specific conductivity and total phosphorus show no clear long-term trends. The variability within a year reflects both seasonal variations and complex (and largely undefined) physical, chemical and biological processes.

  Figure 8.21-3 presents the similar long-term analysis of water quality data at another USGS station near West Newbury. Data for heavy metals and organics are limited. The long term trends for these substances are not known. Available data indicate that with the exception of increases (improvement) in dissolved oxygen levels, the water quality has not changed appreciably during the past few years and remains

TABLE 8.21-3. MASSACHUSETTS WATER QUALITY STANDARDS FOR CLASS SB AND B WATERS

PARAMETER	CRITERIA* FOR CLASS B (FRESH) WATERS:	FOR CLASS SB (MARINE) WATERS:
1. Dissolved Oxygen	Shall be a minimum of 5.0 mg/l in warm water fisheries and a minimum of 6.0 mg/l in cold water fisheries.	Shall be a minimum of 85 percent of saturation at water temperatures above 77°F (25°C) and shall be a minimum of 6.0 mg/l at water temperatures of 77°F (25°C) and below.
2. Temperature	Shall not exceed 83°F (28.3°C) in warm water fisheries or 68°F (20°C) in cold water fisheries, nor shall the rise resulting from artificial origin exceed 4.0°F (2.2°C).	None except where the increase will not exceed the recommended limits on the most sensitive water use.
3. pH	Shall be in the range of 6.5-8.0 standard units and not more than 0.2 units outside of the naturally occurring range.	Shall in the range of 6.5-8.5 and not more than 0.2 units outside of the naturally occurring range.
4. Total Coliform Bacteria	No standard.	Shall not exceed a median value of 700 MPN per 100 ml and not more than 30% of the samples shall exceed 1000 MPN per 100 ml during any monthly sampling period, except as provided in 310 CMP 4.02(1).
5. Fecal Coliform Bacteria	Shall not exceed a log mean for a set of samples of 200 per 100 ml, nor shall more than 10% of the total samples exceed 400 per 100 ml during any monthly sampling period,except as provided in 310 CMR 4.02(1).	No standard.

*Adopted September 1, 1978; approved by the U.S. EPA February 22, 1979.

TABLE 8.21-4. MERRIMACK RIVER WATER QUALITY AT PROPOSED MDC DIVERSION LOCATION.

PARAMETER	MEAN	RANGE	MCL[a]
GROUP I - Indicators (units in mg/l unless otherwise indicated)			
Temperature (^{o}C)	11.7	0.2-25.0[b]	
Dissolved oxygen	10.4	5.6-13.8[b]	
pH (Standard Units)	6.3	5.3-7.2[c]	
Alkalinity, as CaCO3	10	5-16[c]	
BOD_5	3.6	3.0-4.5[d]	
COD	15.6	1-29[c]	
Tot. dissolved solids	64	30-84[a]	
Tot. suspended solids	8.4	<1-33[c]	
Chloride	12.8	6-22[c]	
Fluoride, dissolved	0.1	0.1-0.2[b]	1.4-2.4[e]
Sulfate, dissolved, as SO4	10.2	6.5-15[b]	
Turbidity (NTU)	1.0	0.2-2.2[c]	1
Total organic carbon	4.8	2.9-5.9[c]	
GROUP II - Bacteria (counts/100ml) Algae (Cells/ml)			
Total coliforms	11,800	1,400-38,000[c]	1
Fecal coliforms	542	50-2,800[c]	
Total algae	4,552	168-22,700[c]	
Chlorophyll *a* ug/m^3	3.66	1.08-6.23[d]	

TABLE 8.21-4. (Continued)

PARAMETER	MEAN	RANGE	MCL[a]
GROUP III - Nutrients (mg/l)			
Ammonia, as N	0.21	0.05-0.65[c]	
Nitrate, as N	0.3	<0.1-0.43[c]	10
Phosphorus	0.13	0.10-0.14[d]	
GROUP IV - Metals (units in µg/l unless otherwise indicated)			
Arsenic	1.5	1-3[b]	50
Barium	<50.0	<1-100[b]	1000
Cadmium	<1	<1[b]	10
Chromium	25	10-40[b]	50
Copper	6	4-10[b]	
Iron (mg/l)	0.46	0.26-0.70[c]	
Lead	8	2-33[b]	50
Manganese (mg/l)	0.064	0.04-0.10[c]	
Mercury	<0.1	<0.1[b]	2
Nickel	2	1-3[b]	
Selenium	<1	<1[b]	10
Silver	<1	<1[b]	50
Sodium, dissolved (mg/l)	11.2	4.6-17[b]	
Zinc	18	10-20[b]	

TABLE 8.21-4. (Continued)

PARAMETER	MEAN	RANGE	MCL[a]
GROUP V - Organics (units in µg/l unless otherwise indicated)			
Oils and grease (mg/l)	<18	<1-140[b]	
Phenols	4	3-5[b]	
Aldrin	<0.01	<0.01[b]	
Chlordane	<0.1	<0.1[b]	
DDT	<0.01	<0.01[b]	
Endosulfan	<0.01	<0.01[b]	
Endrin	<0.01	<0.01[b]	2
Heptachlor	<0.01	<0.01[b]	
Lindane	<0.01	<0.01[b]	4
Methoxychlor	<0.01	<0.01[b]	100
Mirex	<0.01	<0.01[b]	
PCBs	<0.06	<0.01-0.10[b]	
Toxaphene	<1	<1[b]	5
GROUP VI - Radioactivity, dissolved (pCi/l)			
Gross Alpha, as natural U	<0.25	<0.5-0.5[b]	5
Gross Beta, as CS^{137}	1.8	1.4-2.1[b]	
Gross Beta, as Sr/Y^{90}	1.7	1.4-2.0[b]	

[a] MCL = maximum contaminant level permitted by Federal drinking water standards; applies only to certain parameters.

[b] Mean and range based exclusively on USGS data for water year 1980, taken near Lowell intake.

[c] Mean and range based on composite of data from: MDWPC station at Route 113, USGS, and other MDWPC stations near Lowell intake.

[d] Mean and range based only on data from MDWPC sampling station at Route 113.

[e] Allowable limit dependent on water temperature.

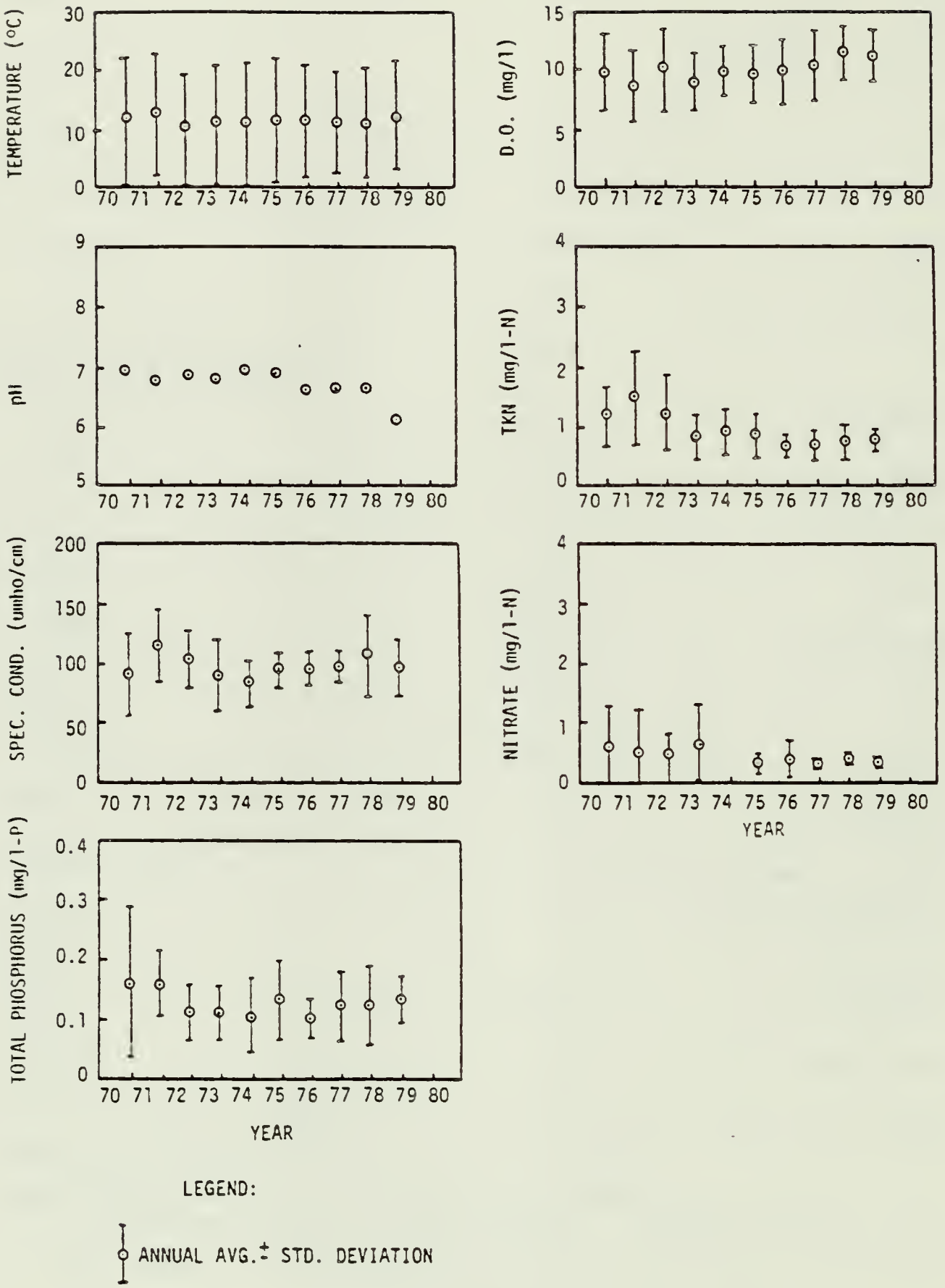


Figure 8.21-2. Long term trend of water quality of Merrimack River at Lowell water intake (USGS Station 01096550).

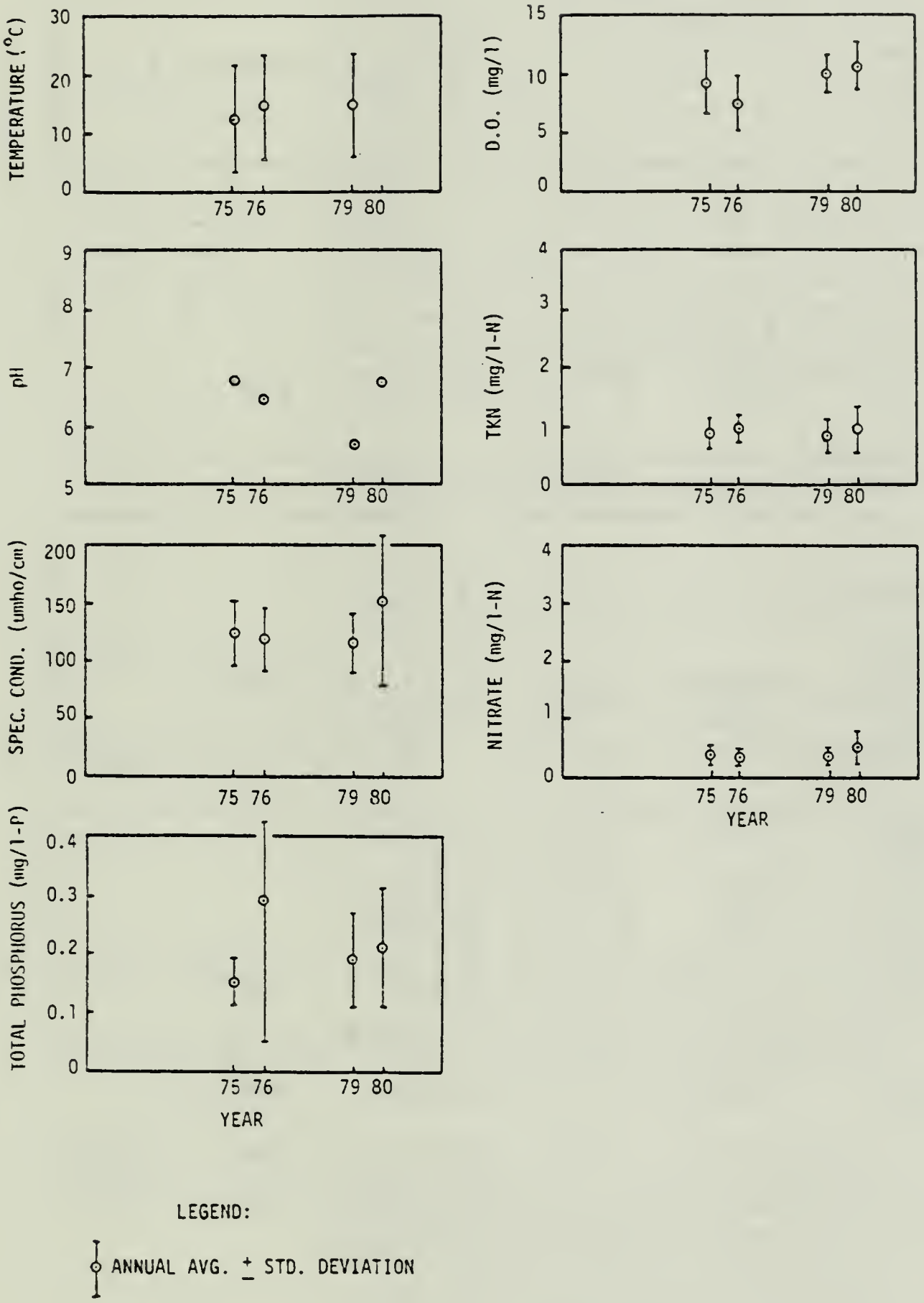


Figure 8.21-3. Long term trend of water quality of Merrimack River near West Newbury (USGS Station 01100750).

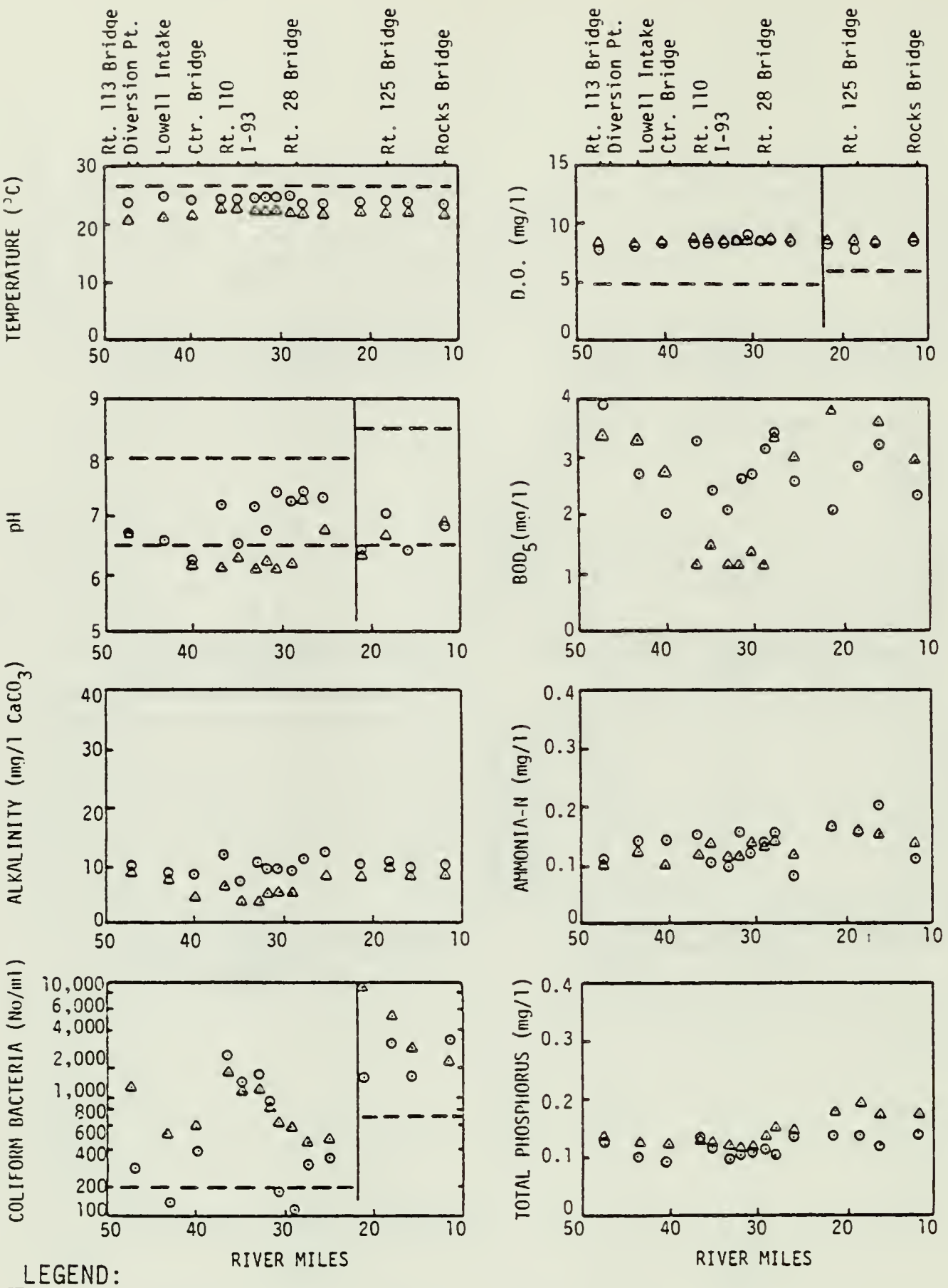


Figure 8.21-4. Merrimack River water quality, summer 1981 (MDPC data).

reasonably good at this downstream location. From the standpoint of downstream impact due to the diversion, the concentration profiles of some key water quality parameters are presented using the most recent data from MDWPC on the Merrimack River (Figure 8.21-4). These data were collected during two surveys in the summer of 1981. In general, water quality in the summer months is depressed due to the elevated temperature and reduced river flow as com- pared with other times of the year. Thus, the pro- files in Figure 8.21-4 represent worst case conditions encountered during 1981. The Massachusetts water quality standards (temperature, pH, dissolved oxygen and coliform bacteria) are also shown for comparison purposes in Figure 8.21-4. This Figure indicates that the water quality condition in the Merrimack River is generally good except for violation of coliform bacteria standards.

- Wastewater Discharges - Major municipal wastewater discharges in the Merrimack River within the study area are listed in Table 8.21-5.

TABLE 8.21-5. MAJOR MUNICIPAL WASTEWATER DISCHARGES.

FACILITY	RIVER MILE	TREATMENT LEVEL	NPDES PERMIT FLOW (mgd)	LIMIT-ATIONS BOD (mg/l)
Lowell	37.0	Secondary	26.0	30
Greater Lawrence	26.5	Secondary	43.0	30
Haverhill	17.2	Secondary	18.1	30
Amesbury	6.6	Secondary	1.9	30
Newburyport	2.3	Secondary	3.4	30

Major industrial wastewater dischargers include Western Electric Company; General Electric Company; Coastal Metal Finishing Company; Nye's Jap Enamelac, Inc.; Westford Anodizing Company; Commodore Foods, Inc.; New England Apple Products, Inc.; Kenics Corporation; and Tewksbury State Hospital. The latest surveys of these discharges were conducted in May and July, 1981, by MDWPC (1982). Among those surveyed, two were discharging directly into the Merrimack

River: The General Electric Company facility in Lowell and the Western Electric Company facility in Lawrence. Neither discharge to the Merrimack River is considered significant in terms of pollutant loadings of BOD, pH, solids, nutrients and metals.

- Nonpoint Sources of Pollution - A number of nonpoint source stations were sampled during 1978 by MDWPC (1979). These sources do not provide significant loadings to the Merrimack River except for coliform bacteria.

- Sediment Chemistry - There is concern over the impact on water quality due to contaminated sediments, if any, in the Merrimack River near the proposed water intake. Historical data to the river from Lowell to Lawrence (USEPA, 1981) and the results of the sample analysis are summarized in Table 8.21-6. The locations of stations sampled by EPA are shown in Figure 8.21-1. The results indicate relatively low levels of heavy metals and PCB in the sediments of the Merrimack River.

- Water Quality and Sediment Interactions - Table 8.21-4 indicates that very low levels of selected heavy metals and pesticides in the surface water samples were reported over the years. In fact, the water quality of the Merrimack River has improved significantly over the past decade because of pollution control. Analysis (1983) also indicates low concentrations of these pollutants (metals, toxic organics, and PCB's) in the Merrimack River sediments. Sediment contaminants are normally unavailable for release to the overlying waters in significant amounts, therefore concentrations of these pollutants in the overlying waters are likely to be extremely low, probably non detectable.

II. Future Conditions Without Alternative - This section describes future water quality conditions in the Merrimack River near the diversion point. The water quality conditions are assessed for three time periods: 1990, 2000, and 2020, assuming that the diversion is not constructed and transfer of water by MDC does not occur.

The assessment is based on limited data on future changes in land use and population in the watershed which contributes changes in the background water quality in the Merrimack River. Due to the limited data available (e.g., local land use and population projections for years 2000 and 2020 are usually sparse), the analysis is somewhat qualitative. The analysis presented in this report is, therefore, the best possible given the data available.

TABLE 8.21-6. SUMMARY OF SEDIMENT DATA FOR THE MERRIMACK RIVER (Dry weights). VALUES IN ug/kg UNLESS NOTED OTHERWISE.

		1981[a]		1983[b]	
	DETECTION LIMIT (mg/kg)	MEAN	RANGE	MEAN	RANGE
Antimony (mg/kg)		<0.5	<0.2-2.5		
Arsenic (mg/kg)		4.73	1.04-12.0	0.62	0.33-0.97
Beryllium (mg/kg)		<1.0	<1.0		
Cadmium (mg/kg)		1.0	1.0	0.17	0.08-0.44
Chromium (mg/kg)		--	--	11.2	8.3 -14
Copper (mg/kg)		34.4	5.0-110.0		
Lead (mg/kg)		52.0	10.0-100.0	10.2	9.7 -12
Mercury		0.3	<0.1-0.7	<3	<2 -<5
Nickel (mg/kg)		14.0	10.0-20.0		
Selenium (mg/kg)		<0.2	<0.2		
Silver (mg/kg)		<1.0	<1.0		
Thallium (mg/kg)		<0.2	<0.2		
Zinc (mg/kg)		83	33-200	28	23 - 31
Cyanide (mg/kg)		<1.2	<1.0-2.0		
Phenols (mg/kg)	10	<0.2	<0.2		
Acenapthene	10	P			
Acenaphthylene	10	P			
Anthracene	10		<10.0-36.0		
Benzo (K) Fluoranthene	10	P			
Benzo (a) Pyrene	10	P			
N-Butyl Benzyl Phthalates	10	<10.0-P			
Chloroform	10	<10.0			
Chrysene	10	P			
Fluoranthene	10	P	P-14.0		
Fluorene	10	P			
Naphthalene	10	P			
Pyrene	10	P	P-10.0		
Toluene	10	<10.0	<10.0		
Di-N-Octyl Phthalate	10	<10.0	<10.0-P		
Bis(2-Ethylhexyl) Phthalate	10	<10.0	<10.0-32.0		
Di-N-Butyl Phthalate	10	<10.0	<10.0		

TABLE 8.21-6. (Continued)

	DETECTION LIMIT (mg/kg)	HISTORIC MEAN	HISTORIC RANGE	1983 MEAN	1983 RANGE
Aldrin	Not Available for these parame-ters	ND			
Chlordane			ND-11		
DDD		ND			
P,P'DDE		1.9			
O,P'DDE		ND			
DDT		ND			
P,P'DDT		4.5			
O,P'DDT		0.8			
Diazinon		ND			
Dieldrin		ND			
Endrin		ND			
Ethion		ND			
Heptachlor		ND			
HeptachlorEpoxide		ND			
Lindane		ND			
Malathion		ND			
Methoxychlor		ND			
Methyl Parathion		ND			
Methyl Trithion		ND			
Parathion		ND			
Trithion		ND			
Toxaphene		ND			
Aroclor 1260 PCB			ND-3		
Aroclor 1254 PCB		ND			
Aroclor 1248 PCB		ND			
Aroclor 1242 PCB		ND		<8	<1-21
COD (mg/kg)		10,800	190-24,000		

[a] U.S.EPA, 1981

[b] NAI, 1983

P - Present but not quantifiable

ND - Not detected

Table 8.21-7 shows the population increases predicted for years 1980, 1985, 1990, 1995, 2000 and 2020 for various towns within the drainage basin. Population growth in two of these towns, Dunstable and Tyngsboro, could potentially have effects on water quality at the diversion point. These data are derived from a 1978 study on land use and water quality in northern Middlesex County (208 program) and the MDC Water Supply Study and EIR. Table 8.21-7 indicates that population in these towns in the Merrimack River watershed is expected to increase significantly except in Lawrence, where population is projected to decline. The increase in population projected for these towns ranges from less than 1% to 20% per 5-year period. Population data for New Hampshire has not been examined in detail, but based on a 1978 study conducted by the New Hampshire Water Supply and Pollution Control Commission, population is expected to increase 22% from 1980 to 2000 within the entire New Hampshire portion of the Merrimack Basin.

Despite the high rate of projected increase in population in some communities, the impact on the Merrimack River water quality is not believed to be significant for several reasons. The major water quality degradation problem in the study area appears to be the result of sewage discharges emanating from New Hampshire communities and the City of Lowell (Northern Middlesex Area Commission, 1978). Point source wastewater control in the past decade by measures such as the construction of Duck Island wastewater treatment facility in 1981, has resulted in significant improvement in the water quality of the Merrimack. This improvement trend will continue as additional control measures are implemented. Nashua, New Hampshire, for instance, is scheduled to have full secondary treatment by 1990. Manchester, New Hampshire already has secondary treatment.

The stormwater loadings, resulting from residential development in the years to come will not be significant from the standpoint of receiving water. The Merrimack, being a large and relatively swiftly flowing river with a large assimilative capacity, is not highly sensitive to changes in stormwater volumes (Northern Middlesex Area Commission, 1978). Also, since the area where its water quality problems are most severe is highly developed, it appears that future development patterns in and around the Lowell area will not significantly affect its future water quality. As the existing combined sewer overflows are ameliorated, swimming and fishing can once again be feasible and safe (Northern Middlesex Area Commission, 1978). Parts of the river where the current is slow could be developed for swimming, while the river will continue to support a fairly diverse fish population. When the fish

TABLE 8.21-7. POPULATION FOR MASSACHUSETTS TOWNS IN YEARS 1980, 1985, 1990, 1995, 2000 and 2020[a,b]
(MERRIMACK RIVER BASIN NEAR DIVERSION POINT)

TOWN	1980	1985	1990	1995	2000	2020
Billerica[c]	36,727	ND	39,624	ND	44,995	54,879
Chelmsford[c]	31,174	ND	32,411	ND	35,473	40,783
Dracut	23,542	26,367	29,531	31,893	ND	ND
Dunstable[d]	1,831	2,197	2,570	2,827	ND	ND
Pepperell	7,933	9,418	10,830	11,913	ND	ND
Tewksbury	27,266	30,047	33,051	35,033	ND	ND
Tyngsboro[c,d]	5,683	ND	7,722	ND	8,999	11,406
Westford	14,926	18,657	22,854	26,740	ND	ND
Lowell	95,000	98,000	100,000	102,000	ND	ND
Andover	29,311	34,571	36,868	38,984	39,100	ND
Lawrence	66,500	66,300	66,000	66,000	66,000	ND
Methuen	42,000	46,500	51,000	55,500	60,000	ND
North Andover	20,129	ND	17,937	ND	22,562	32,384

[a] Northern Middlesex Area Commission, 1978.
[b] Merrimack Valley Planning Commission, 1979.
[c] MDC Water Supply Study and EIR-2020. Task 1: Water Demand Projections Interim Technical Report, Appendices. January, 1983.
[d] Towns for which population growth could have potential effects on water quality at the diversion point.

ND = No data

passage facilities are completed at the Pawtucket dam, anadromous fish runs will return to much of the Merrimack River. The Merrimack's potential for boating, already high, could be further enhanced by aesthetic and qualitative improvements in its water quality.

Based upon the above discussions, we conclude that the overall water quality in the Merrimack is not expected to decrease in future years even with continued population growth. The opposite will occur; continued overall improvement in water quality and enhanced recreational use.

8.21.2 Future Conditions With Alternative

In assessing the water quality impact due to the proposed diversion, the flows of the Merrimack River have been considered first. The most direct impact of the diversion is on the river flow which in turn can affect water quality downstream from the diversion point.

The assessment of safe yield for flood skimming from the Merrimack River was based on the constraints of the U. S. Army Corps of Engineers (COE) study in 1977 and some updated estimates of hydropower water requirements along the Merrimack River within the study area. The COE study identified three major water needs for the Merrimack River: water quality, hydroelectric power and anadromous fish restoration.

According to Bechtel (Merrimack River Diversion Update On Downstream Flow Controls, 1982), the downstream flow needs for hydropower have significantly increased since the COE needs survey study. This is mainly due to the construction of new hydroelectric power generating facilities on the Merrimack River. In fact, the reported water need for downstream hydroelectric power is now three times the value presented in the COE study. These flow requirements are presented in Table 8.21-8.

Diversion of the water from the Merrimack River will be allowed when the flows at Lowell are in excess of the anadromous fish requirements (Figure 8.21-5). These minimum flow requirements at Lowell are also shown in Figure 8.21-5 along with the 7-day, 10-year low flow (7Q10; 934 cfs according to the USGS estimate). The 7-day, 10-year low flow at Lowell is far below the study flow constraints at Lowell.

The 7-day, 10-year low flow is commonly used and adopted by MDWPC for waste load allocation and water quality modeling purposes, but is inappropriate for this case. Since there will be no diversion when river flow is below this minimum flow, water quality impact analysis is based on meeting the

TABLE 8.21-8. ALLIED WATER FLOW NEEDS[1] (cfs) MERRIMACK RIVER AT LOWELL, MASSACHUSETTS.

MONTH	WATER QUALITY[2]	HYDROELECTRIC POWER COE[3]	HYDROELECTRIC POWER CURRENT / FUTURE[4]	ANADROMOUS FISH RESTORATION PROGRAM[5]	AVERAGE MONTHLY
January	980	3,500	11,000 / 12,000	2,000	5,000
February	980	3,500	11,000 / 12,000	2,000	6,200
March	980	3,500	11,000 / 12,000	6,000	10,400
April	980	3,500	11,000 / 12,000	6,000	17,000
May	980	3,500	11,000 / 12,000	4,000	9,600
June	980	3,500	11,000 / 12,000	4,000	5,000
July	980	3,500	11,000 / 12,000	3,500	3,000
August	980	3,500	11,000 / 12,000	3,500	2,400
September	980	3,500	11,000 / 12,000	3,500	2,200
October	980	3,500	11,000 / 12,000	3,500	3,000
November	980	3,500	11,000 / 12,000	3,500	3,000
December	980	3,500	11,000 / 12,000	2,000	5,400

[1]The values presented are not additive. For example, a flow rate of 11,000 / 12,000 cfs is sufficient to meet all three requirements.

[2]Same number as was presented in COE NEWS study of 1977. This number appears reasonable based on dicussions with DEQE Division of Water Pollution Control, which assesses a minimum flow value of 987 cfs (7-day, 10-year discharge) just downstream of Lowell.

[3]U.S. Army Corps of Engineers, 1977.

[4]From Locks and Canals, Inc., Lowell, Massachusetts

[5]Numerical values were developed for COE NEWS study of 1977 by Jason M. Cortell and Associates, Inc., Wellesley Hills, Massachusetts. Based on discussions with this company, the required flow needs may now be less since the quality of the Merrimack River water has improved over the last ten years.
Bechtel Civil & Minerals, Inc. (1982)

water requirements in Table 8.21-8, using the anadromous fish requirements identified in the 1977 COE study as in Arthur D. Little, (1983).

Figure 8.21-5 shows the characteristics of the anadromous fish flow requirements based on historical data. Since the maximum treatment plant capacity planned for the withdrawal is 235 MGD, only a 362 cfs withdrawal is possible. Withdrawal can be made over 80% of the time during the months of January, February, March, April and May, with April being the highest at over 98%. The results of the safe yield analysis predicted an average actual withdrawal during April of 198 MGD (or 306 cfs). On the other hand, diversion can be allowed no more than 20% of the time in July and August (Figure 8.21-6). However, no withdrawals from the Merrimack River are anticipated for the period of July through October (Arthur D. Little, 1984). The maximum percent diverted during any one month (simulated) occurred in a January with 14.8% diverted (Arthur D. Little, 1984).

The river's volume has a direct bearing on the concentration of influents received. Since the exact amount of the inputs of some conservative substances from the areas downstream of the proposed diversion point is not known, it is difficult to derive an accurate estimate of the increase in these concentrations within the river due to flow reduction. Nevertheless, given a maximum decrease in flow of 15%, the maximum increase in concentrations (worst case condition) would be 15%, assuming all the inputs are downstream of the proposed diversion. Dispersion of the inputs by the river flow and dilution by downstream tributories will lessen this impact. This very conservative method of assessing the impact results in a suspended solids increase of 1 mg/l, for example, which is not considered to be significant.

The next consideration is the impact of diversion on some non-conservative substances such as dissolved oxygen and nutrients. The water quality parameters of concern are identified by evaluating the time and space scales associated with these parameters in the Merrimack River. Historic data indicate that the time-of-travel from the proposed diversion point to the mouth of the river is on the order of days when considering the tidal effects in the estuarine portion. Reduction of freshwater will increase the time-of-travel. The effect of diversion on the river flow reduction is estimated to be sustained from the proposed diversion point to the mouth of the Merrimack (over 40 miles), although the volume of water diverted will be reduced to 5 percent at the Essex dam in Lawrence. Thus, the time scale is days and the space scale is 30 or 40 miles when assessing the water quality impact.

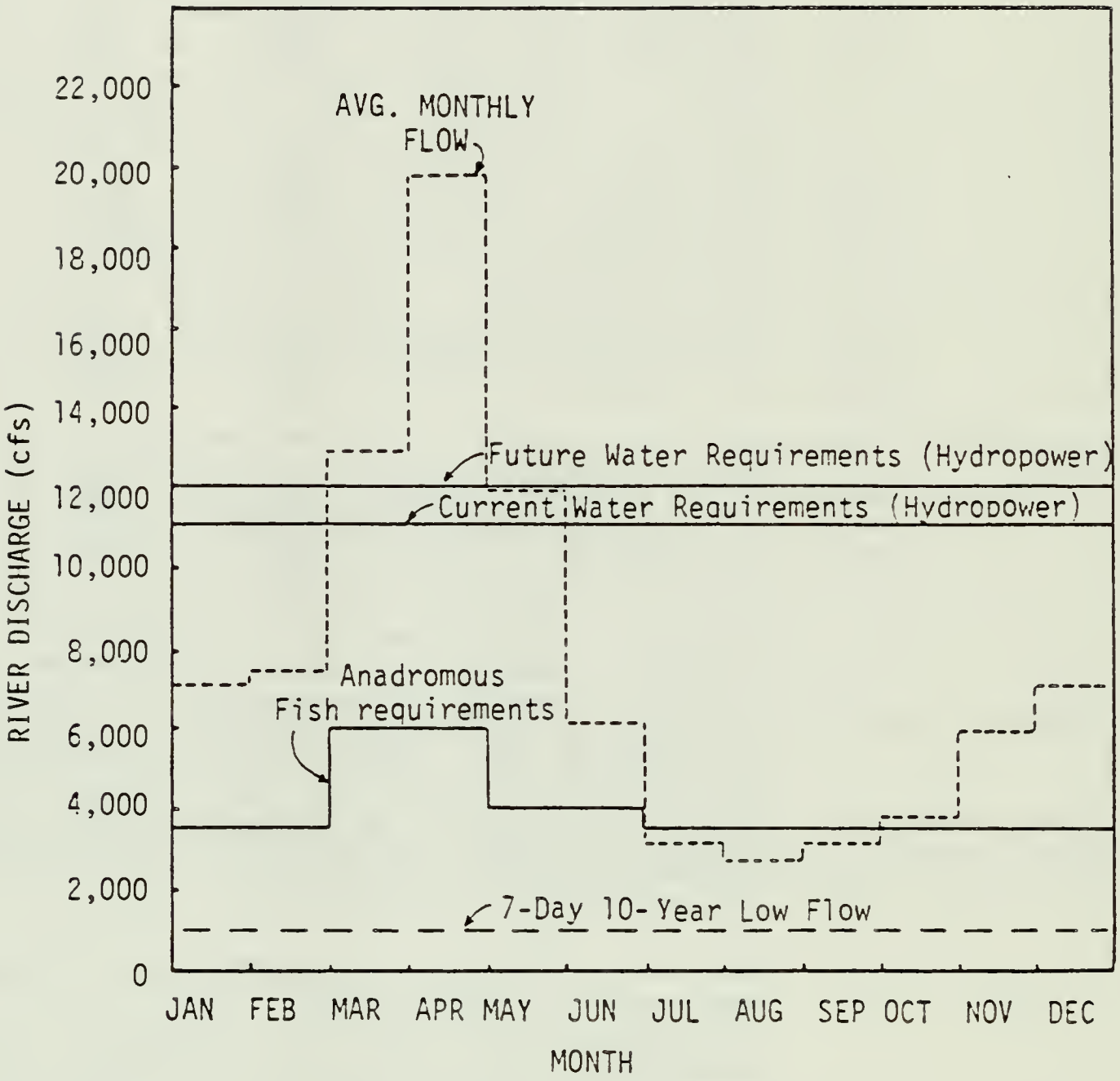


Figure 8.21-5. Historical flow rates in the Merrimack River near Lowell.

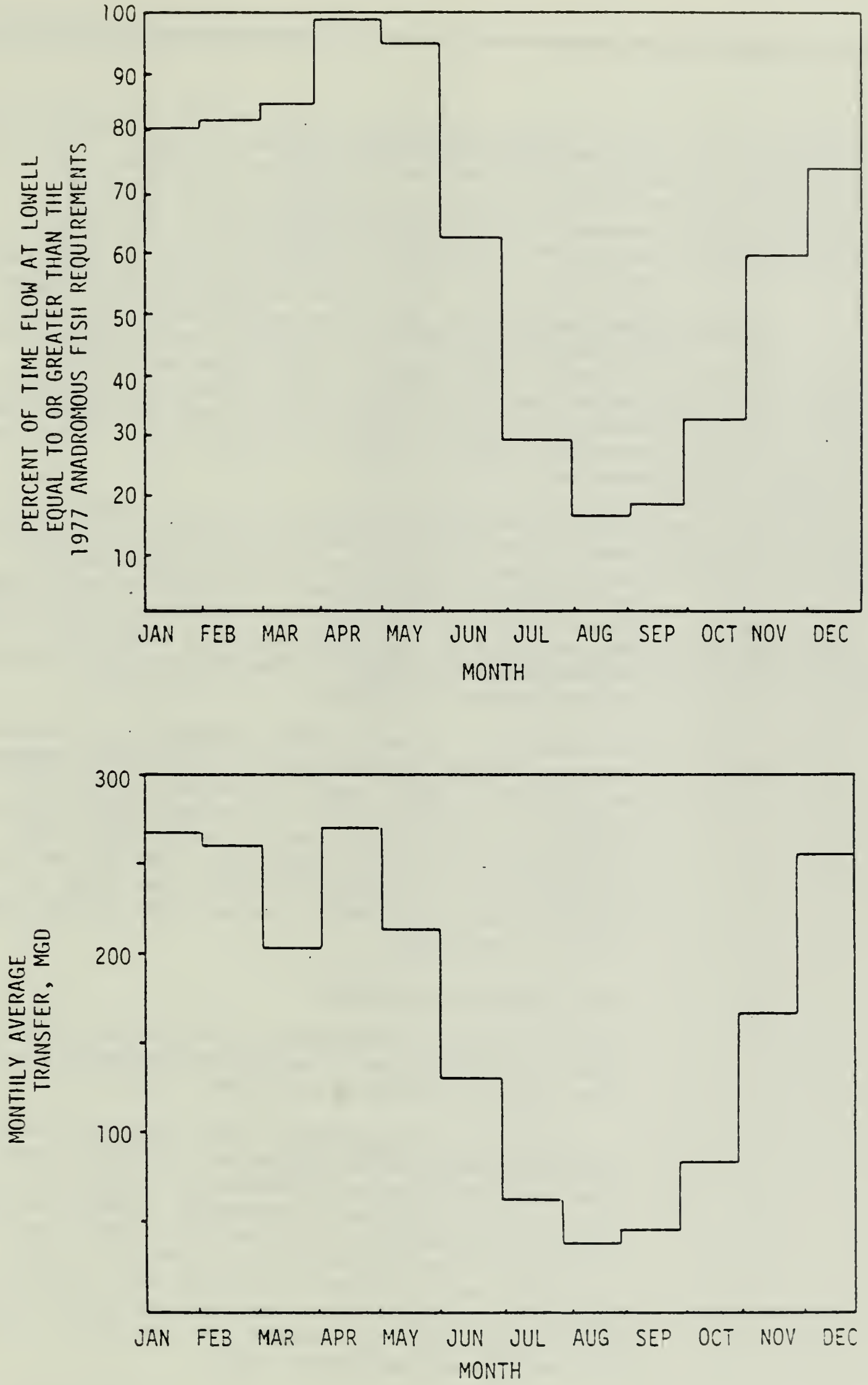


Figure 8.21-6. Monthly average transfer and monthly frequency of potential withdrawal based on a 50 year record, 1930-1979. (Arthur D. Little, 1983).

An EPA (1979) assessment of time and space scales for water quality within riverine environments suggests that the most significant water quality problems over this period of time and this distance would result from increases in concentrations of coliform bacteria and nutrients and from depression of dissolved oxygen levels. The relative concentrations of these parameters along the study section of the Merrimack River makes the water quality impact to them (particularly dissolved oxygen) most important. While the BOD-DO relationship in riverine and estuarine systems is readily understood, bacteria decay and nutrient interactions require data such as decay rate and reaction rates, which are not available for the Merrimack River. Therefore, only the dissolved oxygen impact is assessed in detail.

To assess the impact of diversion on the dissolved oxygen levels in the Merrimack River, a minimum river flow (at Lowell after diversion) of 3,500 cfs and a maximum temperature of 28°C are used. A simplified methodology which utilizes a one-dimensional dissolved oxygen modeling framework is used. The use of such a simplified methodology is justified in view of the data availability and constraints of the study (Section 5.21.2).

The results of the calculation indicate that the minimum dissolved oxygen level in the Merrimack River remains above the standard (5 mg/l) under the project (diversion) condition. The reduction of dissolved oxygen levels due to diversion is small (less than 0.2 mg/l) under this combination of flow and temperature. That is, as long as minimum flow is not below 3,500 cfs, the impact of diversion upon the dissolved oxygen level in the Merrimack River is very small.

8.21.3 Significant Impacts

Based on the above assessment no significant water quality impacts resulting from diverting the projected range of water from the Merrimack River were identified.

I. Measures of Significance - The significant impacts were identified based on the available, historical data for the water quality parameters presented in Section 8.21.1.I. Data were also compiled on wastewater discharges, nonpoint sources, and sediments which may affect water quality conditions. The changes in concentrations of the parameters were evaluated where data were available to assess the project's water quality impact. The changes were compared to State standards set to protect the Merrimack Rivers designated uses.

II. Significant Issues - Since there are major industrial discharges to the Merrimack below the proposed diversion point and since there are no available data on organic priority pollutants, field investigations would be necessary to determine organic priority pollutant levels if the Merrimack River becomes the Preferred Alternative.

8.21.4 Mitigation/Enhancement Measures

- The water quality impact assessment was based on meeting the flow requirements of the Merrimack Anadromous Fish Restoration program. Therefore, water will not be diverted during flows less than those stipulated for fish restoration. These minimum flows are significantly higher than the 7-day, 10-year frequency low flow, upon which the State bases its water quality protection measures. This policy mitigates any significant water quality impacts of the diversion project.

- To control sedimentation during and after construction, an erosion control plan could be implemented to protect water quality.

8.30 ECOLOGY

In this chapter, the focus is on the aquatic ecology of the Merrimack River, the ecology of the Merrimack River floodplain, and the terrestrial ecology of the Merrimack River Alternative rights-of-way.

8.31 AQUATIC ECOLOGY OF THE MERRIMACK RIVER

8.31.1 Baseline Conditions

I. Existing Conditions

- **Macroinvertebrates**

- Previous Investigations - In the mid-1960's, Oldaker (1966) sampled the benthic macroinvertebrates of the Merrimack River from the New Hampshire state line to the Essex Dam and reported standing crops ranging from 0 to 8212 m^{-2} with relatively low taxonomic richness (1-7 taxa). Organic pollution tolerant taxa dominated throughout most of this section of the river, including worms (Oligochaeta), midges (Chironomidae), and clams and snails (Mollusca) with maximum densities of 2,104; 5,910; and 32 m^{-2}, respectively. Species preferring clean water (i.e. mayflies, stoneflies, and caddisflies) were absent from the benthic collections; those species tolerating septic conditions, nauseous gases, and grease and oil prevailed.

  Macroinvertebrates were collected in September 1973 (NAI, 1974) at two stations between Lowell and Lawrence, Massachusetts. Densities of the most abundant taxa were as follows: Oligochaeta (430 to 690 m^{-2}), Cheumatopsyche sp. (7 m^{-2}) (only at Lowell), Chironomidae (10 m^{-2}) and Chaoboridae (10 m^{-2}) (only at Lawrence) (Aquatic Ecology Appendix Table 8.31.1-1). Using the data presented by Oldaker (1966), NAI (1974) calculated benthic community diversity values, all of which were below 2.0, indicating a stressed system.

  Only 12 benthic macroinvertebrate taxa, represented by Oligochaeta, Hirudinea, Nematoda, Isopoda, Mollusca (Gyrulus, Ferrissia, Unionidae), Diptera (Chironomidae, Ceratopogonidae, Psychoda), and Coleoptera (Gyrinidae, Dubraphia) were collected by the Massachusetts Division of Water Pollution Control (MDWPC, 1974) at four stations from the New Hampshire-Massachusetts state line to the Essex Dam in Lawrence. Substantially more Oligochaeta and Diptera were collected at two stations downriver from Essex Dam than at the four stations between the state line and Essex Dam. Since the mid 1970's, however, water quality has improved dramatically in this section of the Merrimack River. A current benthic survey would be expected to show an increase in benthic community diversity (Bildger pers. comm. 1982).

- Investigations in 1982 - In the summer of 1982, NAI sampled the Massachusetts portion of the Merrimack River between Essex Dam and the New Hampshire state line (Figure 8.31-1), using a ponar grab. A total of 33 taxa were collected (Aquatic Ecology Appendix Table 8.31.2-3), which was nearly three times the number reported by the MDWPC (1974). Oligochaeta still dominated the macrobenthos (73.8%), followed by Diptera (2.7%), Mollusca (1.5%) and Ephemeroptera (1.0%). Caddisflies (Trichoptera) and mayflies (Ephemeroptera) were listed for the first time in at least two decades.

As in the previously described surveys, midges (Chironomidae) were the dominant family among the Diptera. Mollusca were represented in the grab samples by the Sphaeridae, which were well distributed among all collection sites. Tricoptera, dominated by the Hydropsychidae, were also well distributed, showing no shoreward/mid channel distribution trends except below Pawtucket Dam, where more individuals (especially Chematopsyche sp.) were found at mid channel. Odonata, represented by the family Gomphidae, occurred sporadically in the samples. Ephemeroptera were collected almost exclusively from mid channel stations, and were predominantly represented by burrowing taxa (i.e. Ephoron sp.) and lentic taxa (i.e. Caenis sp.).

Densities of all macroinvertebrate samples collected from this section of the Merrimack ranged from 204 to 3837 m^{-2}: these densities were in the low to middle range of densities reported by Oldaker (1966). The modest 1982 density values reflected the effects of sandy substrates which undergo constant shifting, particularly at mid channel, on macroinvertebrate densities and species richness. Oligochaete densities were higher at littoral collection sites (mean: 1160 m^{-2}; range: 82 to 3467 m^{-2}) where substrates shifted less and were coarser grained, than at mid channel (mean: 380 m^{-2}; range: 13 to 1204).

During a five week period in the fall of 1982, NAI investigators set out two types of macroinvertebrate collectors: stacks of multiple ceramic plates, and wire mesh bags filled with rocks, sticks and soil, in the same general vicinity as the ponar grab stations. A total of 21 taxa were recovered from the multiplates, and 20 taxa from the natural substrate-filled wire mesh. In general, the same taxa of macrobenthos were represented in roughly the same proportion as collected with the ponar grab samples. A stonefly (Plecoptera) taxon (Taeniopteryx sp.) was

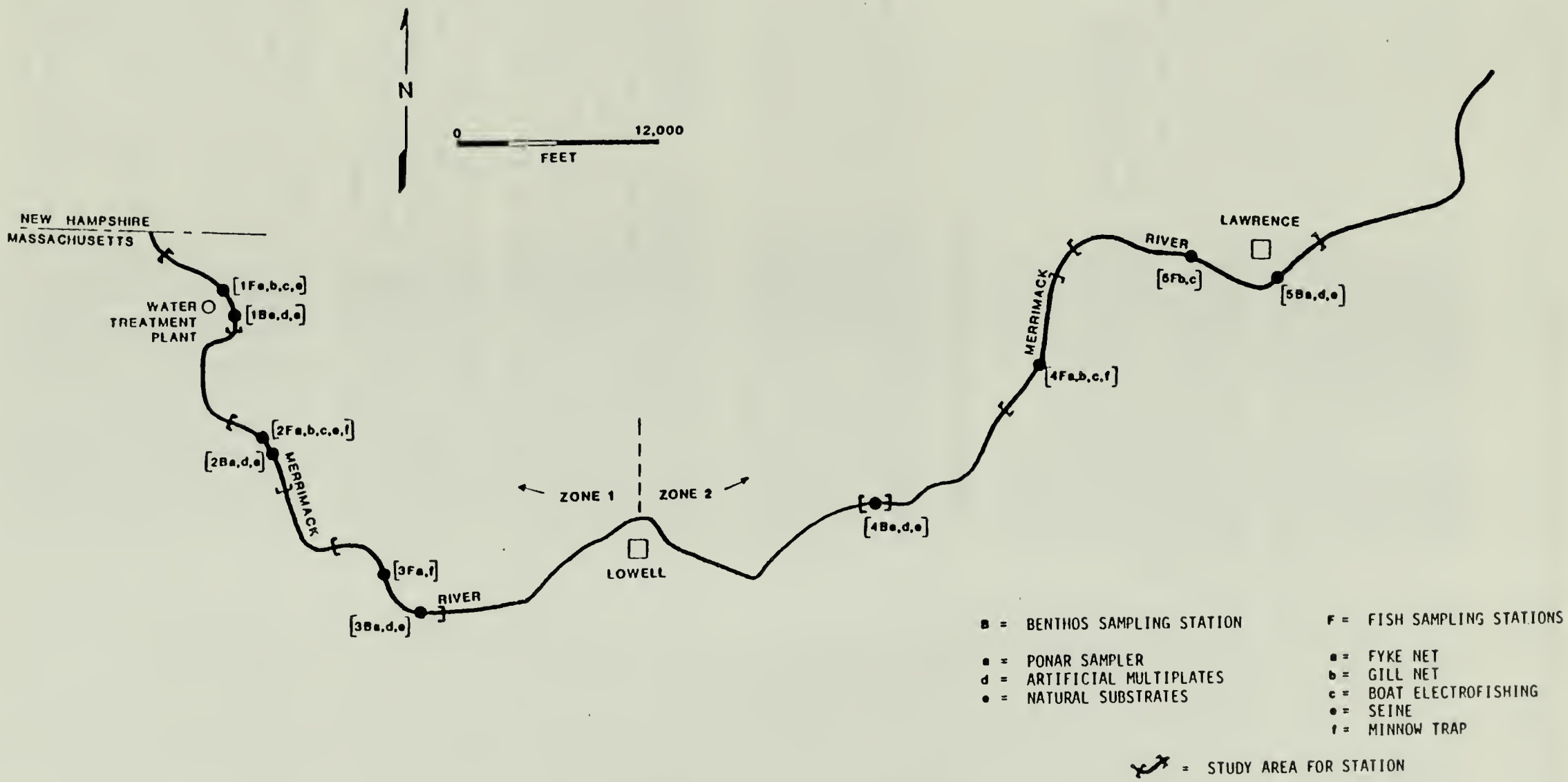


Figure 8.31-1. Benthic Macroinvertebrate and Fish Sampling Stations and Gear Types used during the 1982 NAI Field Studies on the Merrimack River.

recovered using both of the above fall collection techniques, and this species was found throughout the stretch of river from the New Hampshire state line to Lowell, Massachusetts (zone 1). In the multiplate samples, Hydroptilidae, in addition to Hydropsychidae, were predominant among the Trichoptera. Mollusca were represented in the multiplate samples by Planorbidae but not by Sphaeriidae. Planorbidae (snails) are more mobile than Sphaeriidae (clams). Both molluscan families were found in the natural substrate-filled wire mesh collectors, along with representatives of Bithyniidae (an exotic species) and Ancylidae. Other taxa, unique to the wire mesh collectors, were Agraylea, Neuroclipsis, Neurocordulia, Pyralidae, and Lepidoptera.

- Finfish

- Previous Investigations

Migratory Species - Surveys conducted from June 1968 through September 1969, by the Massachusetts Division of Fish and Game (MDFG) (Otis and Bridges 1969) listed three anadromous species and one catadromous species (Aquatic Ecology Appendix Table 8.31.1-2). A fifth transient, the mummichog, is probably a resident of salt marsh ponds.

Since 1969, four additional anadromous species have been collected or observed (Aquatic Ecology Appendix Table 8.31.1-2; Knight pers. comm. 1982; Henry pers. comm. 1982). In 1981, 13 Atlantic salmon returned to the base of Essex Dam in Lawrence, Massachusetts, in addition to Atlantic sturgeon, and large numbers of sea lampreys. (Iwanowicz pers. comm. 1982).

A fish lift has been in operation at Essex Dam since September of 1982; by November of that year, 16 Atlantic salmon, two American shad, and two blueback herring or alewifes had been observed using the lift to get past the dam (Kuzmeskus pers. comm. 1982).

The Merrimack River, given its topography, climate, hydrology, present water quality and available substrate, possesses great potential regarding spawning and nursery habitats for anadromous species (Kuzmeskus et al. 1982). Following completion of the fishway at Pawtucket Dam in Lowell, Ma. in 1985, and the elevator in 1986 (PCAFMMR 1981), anadromous species such as Atlantic salmon, American shad, blueback herring and sea lampreys can be expected to reoccupy the river above Pawtucket Dam. Sturgeon may be expected to utilize the Merrimack River above

Pawtucket Dam and may now utilize the stretch between Pawtucket and Essex Dams (zone 2, Figure 8.31-1), although this has not been substantiated. Depending on the future strength of east coast stocks, striped bass may or may not use the river above Pawtucket Dam as a nursery area; however, juveniles of this species are expected to occupy Zone 2.

Resident Species - Otis and Bridges (1969) recorded 17 resident fish species for the stretch of the Merrimack River from the New Hampshire border to Pawtucket Dam (Zone 1). White suckers and carp constituted 28% of the total count and 68% of the total weight. Yellow perch, largemouth bass, bluegills, black crappie, pumpkinseeds, bullheads, and white perch together represented only 30% of the count and 20% of the total weight.

The stretch from Pawtucket Dam to Essex Dam (Zone 2) was inhabited by 13 fish species. Chain pickerel, black crappie, white catfish and banded sunfish were absent from Zone 2. Throughout the study area, white sucker, brown bullhead and carp predominated. These "rough" fish, plus goldfish and white catfish, constituted 40% of the total count and 80% of the total weight for the entire study area.

Since the Otis and Bridges (1969) study, water quality in the Massachusetts section of the Merrimack River has improved considerably with a concomitant improvement in the sport fishery expected (Iwanowicz pers. comm. 1982; Knight pers. comm. 1982). More recent fisheries data collected below the Lawrence Dam by the Massachusetts Division of Marine Fisheries personnel from April through June 1979, substantiates such expectations. A trap net program (4.5 inch mesh) was primarily designed to survey anadromous fish; however, a number of resident fish species, including chain pickerel, smallmouth bass, carp, white catfish, black crappie, white sucker, white perch, and blueback herring were also captured.

- Investigations in 1982 - Resident finfish in the Merrimack River study area (Figure 8.31-1) were sampled by NAI in the summer and fall of 1982 to provide information on current species composition. Relying primarily on fyke nets, gill nets and electro-fishing gear, the NAI survey collected a total of 441 fish representing 19 taxa (Aquatic Ecology Appendix Tables 8.31.2-4 and 8.31.2-5). Four species collected in 1982, American eel, red-breasted sunfish, longeared sunfish and smallmouth bass, were not collected by Otis and Bridges (1969). On the other

hand, banded sunfish and goldfish recorded by Otis and Bridges (1969) were not collected by NAI in 1982.

Species of gamefish collected by NAI in the 1982 survey were chain pickerel, largemouth bass, and smallmouth bass. These three species accounted for 11% of the total fish count and 8% of the total weight.

The "rough" fish, white sucker, carp, and American eel, composed 23% of the total count in summer and 40% of the count in fall. By weight, percentages of rough fish were 69% in the summer and 80% in the fall. Fall count and weight percent composition was very similar to rough fish composition reported by Otis and Bridges (1969). These inventory data indicate that while water quality has improved over the 13-year interval, the resident finfish communities have shown no appreciable change in species composition.

- Threatened and Endangered Species - There were no threatened and endangered species observed during the 1982 investigations, nor have any such occurrences been reported from the Merrimack River aquatic ecology study area.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 8.31.1.I, indicator species of macroinvertebrates and fish were selected for the Merrimack River. The term "indicator species" as applied in this report denotes 1) species representative of aquatic habitats, and 2) species sensitive to the kinds of perturbations that may result from development of the Merrimack River alternative. The group of species selected is representative of the trophic levels and habitats within the study area, and within potential project impact areas, and are used to assess impacts of water supply development on these habitats. These species are listed in Table 8.31-1.

  The indicator species were selected on the basis of seven criteria: the criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Water quality in the Merrimack River is adversely affected by wastewater discharges in New Hampshire and Massachusetts and to a lesser extent by non-point source discharges. Land use and population information to the year 2020 is very limited, and the analyses presented in this section are the best available for the years 1990, 2000, and 2020. Based on

TABLE 8.31-1. INDICATOR SPECIES SELECTED FOR THE MERRIMACK RIVER AQUATIC ECOLOGY ASSESSMENT.

FISH	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
White Sucker	*Catostomus commersoni*	Riffle, Pool, Impoundment	Detritivore/ Herbivore Primary Carnivore
Sea Lamprey (Larvae)	*Petromyzon marinus*	Pool	Detritivore/ Herbivore
Brook Trout	*Salvelinus fontinalis*	Riffle, Pool	Primary Carnivore
Smallmouth Bass	*Micropterus dolomieui*	Riffle, Pool	Primary Carnivore Higher Order Carnivore
Atlantic Salmon	*Salmo salar*	Riffle, Pool	Primary Carnivore Higher Order Carnivore
American Shad	*Alosa sapidissima*	Riffle, Pool	Primary Carnivore
Largemouth Bass	*Micropterus salmoides*	Pool, Impoundment	Primary Carnivore Higher Order Carnivore
Redbreast Sunfish	*Lepomis auritus*	Pool, Impoundment	Primary Carnivore

TABLE 8.31-1. (Continued)

MACRO-INVERTEBRATES	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Stonefly	Taeniopteryx sp.	Gravel/Cobble, Litter	Detritivore Herbivore
Mayfly	Ephoron sp.	Sand, Mud	Detritivore
Caddisfly	Cheumatopsyche sp.	Gravel/Cobble	Detritivore Herbivore Carnivore
Caddisfly	Hydroptila sp.	Gravel/Cobble, Sand, Litter	Herbivore
Flies	Chironomus sp.	Sand, Mud, Litter	Carnivore

information available in the area-wide planning study, for the Franklin County, Massachusetts 208 area (1979), and the MDC Water Supply Study and EIR, water quality and aquatic ecology are expected to show improvements because of the elimination of past wastewater discharge problems.

- 1990 - Over the past decade, significant improvements in water quality have been reflected in the establishment of "clean water" aquatic faunal communities. These trends are expected to result in water quality suitable for water contact sports by 1990. Good water quality will promote increased species diversity and a higher biological assimilative capacity.

- 2000 - Aquatic community characteristics will be similar to those predicted for 1990, with a continued trend toward improved species diversity and productivity.

- 2020 - Characteristics of the aquatic communities are not expected to differ substantially by 2020 from those projected for the year 2000.

8.31.2 Future Conditions With Alternative

Short term and long term project impacts on aquatic indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 8.31-2.

I. Short-term Construction Period - Installation of fish screens at the diversion intake will involve dewatering an area of approximately 0.25 acre inside a temporary enclosure for 3 months. Resumption of flow will be accompanied by localized sedimentation which may temporarily disrupt aquatic communities at the diversion site. Benthic indicator species potentially affected by temporary loss of habitat and sedimentation include a detritivore (Ephoron sp.), an herbivore (Hydroptila sp.), and a carnivore (Chironomus sp.). Fish indicator species potentially impacted by sediment if construction were to occur during the nesting period include white sucker (an omnivore), brook trout, smallmouth bass and Atlantic salmon (all carnivores). However, stream communities are accustomed to accommodating naturally occurring sediment influxes during high-water periods, and the proportion of sediment deposited will be small compared to the sediment carried downstream by high flood flows. Moreover, soil erosion during and after construction will be minimized by the implementation of a soil erosion control plan. Based on these considerations, impacts to indicator species will be minimal and re-establishment of the conditions requisite

TABLE 8.31-2. SUMMARY OF IMPACTS OF THE PROPOSED MERRIMACK RIVER DIVERSION ON MACROINVERTEBRATE AND FISH INDICATOR SPECIES.

	HABITAT TYPE						
IMPACT CATEGORIES:	RIFFLE	POOL	LITTORAL	GRAVEL	SAND	MUD	LITTER
Erosion			X				
Water Quality							
Water Quantity	X	X	X				
Water Level	X	X	X				
Habitat Loss/ Change							
Displacement/ Disruption				X	X	X	X
Entrainment/ Impingement			X				
Vegetation Composition Changes							

to the life cycle requirements of fish and macroinvertebrate indicator species populations and aquatic communities will be rapid.

II. Long-term - Water quality projections (see Section 8.21.2) for the Merrimack River with diversion predict that none of the parameters necessary for maintenance of aquatic life would change so as to exceed the natural range of variation. Since the aquatic communities now living in the river have adapted to the natural range of variation it is assumed that the tolerance thresholds of the macroinvertebrate and fish communities and indicator species will not be exceeded so long as flows are high enough to meet the minimum flow requirements of the Merrimack Anadromous Fish Restoration program. However, impingement of migratory and resident sport fish species on the intake screens and entrainment have the potential for locally affecting aquatic communities and species populations. The indicator species most susceptable to entrainment/ impingement impacts would include larval or juvenile shad, white sucker, and Atlantic salmon (smolts).

Effects of changes in water level during diversion on aquatic communities were also assessed. June was selected as the worst case month because it is the low-flow month having the greatest number of days (19) when maximum transfers (235 MGD) could occur (see Section 8.21.2).

Calculations at a section of river having the lowest gradient floodplain demonstrated that, with maximum transfer volumes, the decrease in water level would be about 2 inches and the maximum reduction in lateral flooding would be about 2 feet on each bank. Habitat losses due to reduction in water level during diversion were assessed for: 1) exposure of river channel bottom and subsequent loss of wetted substrate and 2) significant current velocity alterations. With a decrease of 2 feet in lateral flooding occurring at the minimum required June flow of 4000 CFS, the river channel would still be flooded above the top (see Terrestrial Ecology Appendix Section 8.33.2 for transect location figure and calculation methods for flow/stage relationships).

Based on these findings, there will be no loss of wetted substrate, and changes in current velocity will be insignificant, therefore conditions necessary to fulfill habitat requirements of indicator species such as brook trout, smallmouth bass and American shad will not be altered. This indicates no long term effects to aquatic communities or indicator species will occur.

- 1990 - Some changes in macroinvertebrate and fish communities due to the proposed transfers may occur as

a result of impingement and entrainment at the intake structure. Effects due to water quality and water level changes are not expected to differ substantially from those anticipated without the project.

- 2000 - Changes in macroinvertebrates and fish with the proposed transfer in operation will not differ significantly from the baseline projections to this year without the project except for the possibility of slight changes due to impingement and entrainment.

- 2020 - Projections of the macroinvertebrate and fish baseline to 2020 with the project are not significantly different from those without the project except for the possibility of slight changes due to impingement and entrainment.

8.31.3 Significant Impacts

Slight changes in community composition and species populations may result due to impingement and entrainment at the intake structure.

I. Measures of Significance - Macroinvertebrate and fish communities in the Merrimack River between the Essex Dam and the diversion site were characterized based on existing information and field surveys. Indicator species representative of the major habitats and trophic levels which will respond to changes resulting from the project were selected (see "Task 4: Indicator Species Selection"). Project-caused changes in concentrations of water quality constituents affecting aquatic life were evaluated based on the established standards and criteria for maintenance of aquatic life. Species richness, the sensitivity of indicator species and species of special concern to changes in water level and parameter concentrations also provided a basis for judging the significance of project impacts.

II. Significant Issues

- Potential slight changes in community composition and species populations due to impingement and entrainment.

8.31.4 Mitigation/Enhancement Measures

- An impingement/entrainment study at the transfer inlet location to determine species and numbers affected could minimize impacts by influencing the intake design.

- An erosion control plan to control sedimentation during and after construction could be implemented.

8.33 TERRESTRIAL ECOLOGY OF THE MERRIMACK RIVER FLOODPLAIN

An assessment of the vegetation, herpetofauna, avifauna and mammals of the Merrimack River floodplain was conducted. The study area for this assessment included a section of the Merrimack River between a point just above the proposed transfer at Lowell to Essex Dam in Lawrence (Figure 8.33-1). This is the section of river that could be affected by a flow reduction of more than 5% as a result of the transfer. For purposes of this assessment, effects resulting from flow reductions of 5% or less are considered insignificant since such flows are within the range of yearly variability.

8.33.1 Baseline Conditions

Baseline conditions are considered to be those conditions existing in 1982 at the time of the investigations, and projected to 1990, 2000 and 2020 without the project. The assessment of existing conditions was based both on studies conducted by other investigators and upon field investigations conducted in 1982 by NAI. Future conditions were projected based on land use trends. Literature cited, descriptions of field methods, lists of plant and wildlife species and quantitative data are presented in Terrestrial Ecology Appendix Sections 8.33.2 and 8.33.3.

I. Existing Conditions - In the following sections, previous investigations applicable to the Merrimack River floodplain are presented by groups of biota, and the results of field investigations conducted in 1982 are discussed by vegetative community (habitat type).

- Literature Surveys
  - Vegetation

    Regional Vegetation - Based on investigations of the regional vegetation by Braun (1972) the study area lies within the Hemlock--Hardwoods area of the New England section of the Hemlock-White Pine-Northern Hardwoods Region. The Hemlock-Hardwoods area is widespread throughout central New England, and lies within the New England Upland Physiographic area which is hilly, with numerous lakes, providing a diversity of environments for plant communities (Lull, 1968). The Hemlock-Hardwoods area is characterized by a predominance of second-growth stands that vary widely in species composition depending upon soils and land use characteristics. In shrub-lands gray birch and aspen, often in combination with white pine, are generally dominant. Forests

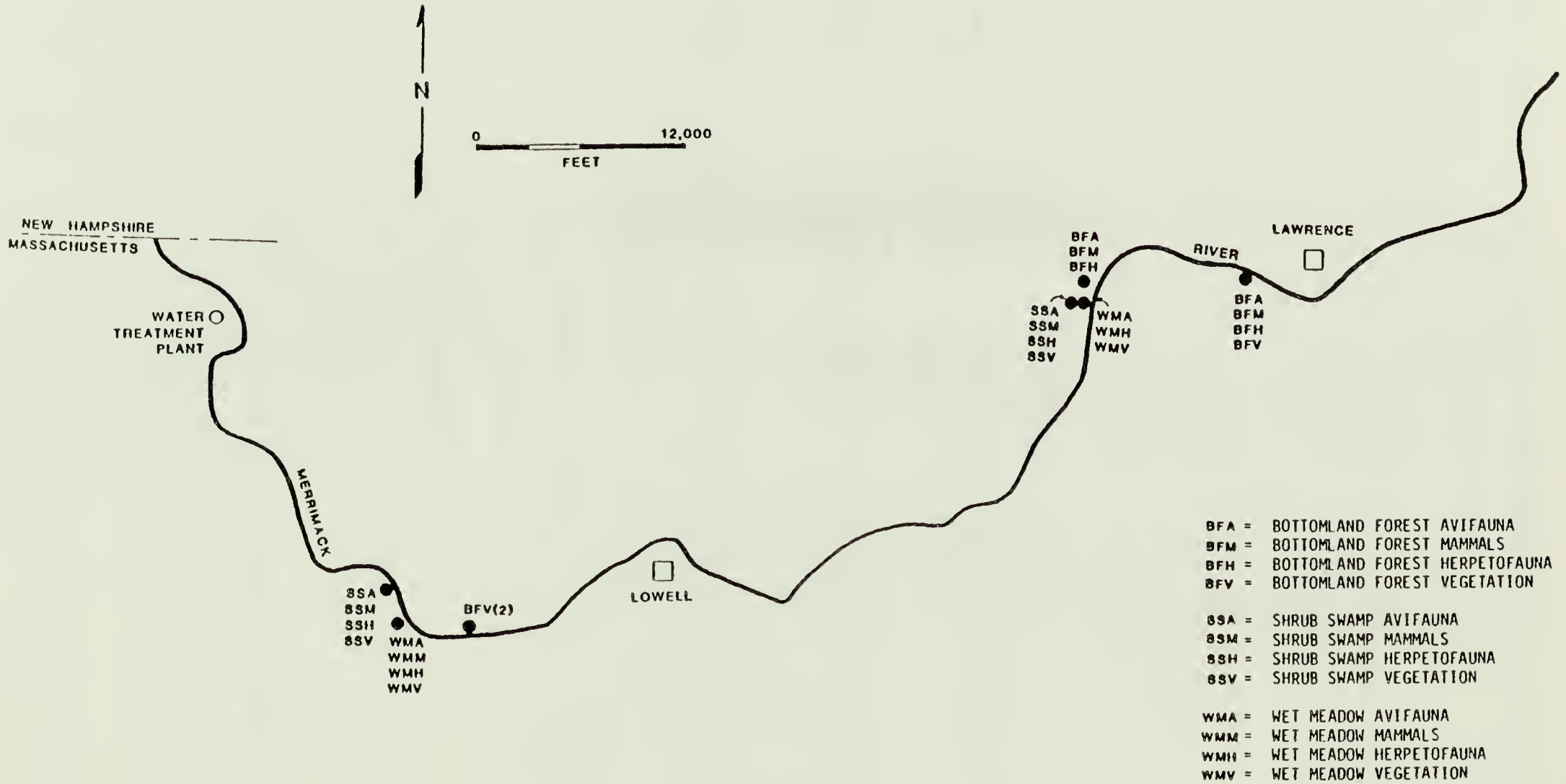


Figure 8.33-1. Floodplain Community Stations on the Merrimack River sampled by NAI in 1982.

that were logged may support stands containing multiple stemmed red oak. On northern slopes or moist sites hemlock may be abundant, or a climax community of hemlock, white pine, beech, yellow birch and sugar maple may be present. Wetland and floodplain communities also vary considerably in species composition depending upon water depth and frequency of flooding.

Floodplain Vegetation No previous investigations of the floodplain vegetation of the Merrimack River are known to have been conducted.

- Herpetofauna - No previous herpetological studies are known to have been conducted on the Merrimack River floodplain between the diversion and Essex Dam. A list of the New England species having ranges that overlap the study area were obtained from Conant (1975) and Lazell (1972). The lists of state rare and local species were obtained from Blodget et al (1982).

  The habitat niche and feeding information for this study was also obtained from the above sources, with additional information taken from the species accounts in Lazell (1976), Wright and Wright (1949 and 1957), Bishop (1941), and Carr (1952).

  The study area for this alternative lies in the coastal lowlands, north of the ranges of many of the warm-climate herpetofauna. Several southern species reach the northern limit of their ranges at this point, such as the Blanding's turtle (Emydoidea blandingi) and the box turtle (Terrapene carolina). Compared with the climate in the vicinity of the Connecticut and Millers/Tullys alternatives, the climate of the Merrimack floodplain is somewhat less severe during winter, due to the ameliorating influence of the nearby ocean water. Of the 36 species with ranges overlapping the study area, there are 7 turtles, 11 snakes, 8 salamanders, and 10 frogs.

- Avifauna -- Information pertaining to breeding ranges of bird species was obtained from Peterson (1980), and from the Breeding Bird Atlas Survey conducted between 1974 and 1979 by the Massachusetts Audubon Society. Specific lists were compiled for this study area by carefully evaluating the latter source and including each

species classified under "probable breeding record" status. The emphasis in evaluating this data was on including all possible species in the baseline species list for the study area.

The Breeding Bird Atlas is compiled based on areas occupying one sixth of a USGS Topographic map which are rectangular in shape and which measure about three miles on each side. Wherever the floodplain included such an area, the atlas list of breeding species was added to the study list.

The avifauna of the Merrimack River study area typically shows a mixture of several types of birds:

1. water-dependent species including waterfowl, marsh and swamp birds, and gulls;

2. northern species at the southern limit of their breeding ranges such as northern junco, whitethroated sparrow, yellow-rumped and Canada warblers;

3. species adapted to artificial food supplies such as house sparrows, pigeons, and starlings;

4. wide-ranging resident species such as the woodpeckers, crows and jays, and titmice;

5. wide-ranging migrant species including most of the warblers, vireos, and fringilids (finches, sparrows, buntings, and grosbeaks)

The first two categories are of primary concern to this project since impacts to water level or quality may alter the ecology of water-dependent species or species at the limit of their breeding ranges.

- Mammals - The mammals of the Merrimack River study area are a mix of both boreal and southern species near the northern limit of their range (Burt and Grossenheider, 1976). Records compiled by the Massachusetts Division of Fisheries and Wildlife indicate that at least 45 species of mammals may occur in the general area of the Merrimack River Valley included in this study (Cardoza, 1979). Evidence of the occurrence of two additional species (European hare and southern bog lemming) is inconclusive. Among the

more typically boreal species known to occur throughout this region are the snowshoe hare, northern flying squirrel, and fisher. Moose also occasionally wander into this region from neighboring Maine and New Hampshire. Southern species near the northern limits of their range include the Virginia opossum, eastern mole, eastern cottontail, and southern flying squirrel (Hall and Kelson, 1959). The eastern coyote has only recently expanded its range into eastern Massachusetts (Mirick, 1983, pers. comm.).

Blodget and Cardoza (1982) list two nongame mammal species from this region for special protection: hoary bat and southern bog lemming. The hoary bat migrates through Massachusetts but its status as a breeding resident is uncertain. The southern bog lemming is probably found throughout the Commonwealth in areas of suitable habitat, but records of its occurrence exist only from Hampshire, Worcester, and Suffolk counties (Cardoza, 1979).

- Field Surveys - Owing to the steepness of the banks aligning both sides of the river within the study area, wetland and floodplain communities were much less common than the terrestrial communities, although there was sufficient area of the former to select representative locations for quantitative sampling.

In the following subsections, the results of the field investigations conducted at locations representative of the floodplain and wetland communities in the study area are discussed for vegetation, herpetofauna, avifauna and mammals. Terrestrial communities were not included because the project would affect only floodplain and wetland types. River channel and bottom communities were also not included because preliminary engineering data indicated that water level reduction will not be of a magnitude to affect these types. The locations of the transects where the studies were performed are shown in Figure 8.33-1. The vegetative types are presented by successional stage where appropriate, beginning with the earliest stage. Similarly, the groups of wildlife associated with each type are presented beginning with the most primitive group. In general, the flora and fauna found to be present in the floodplain and wetland types of the study area were representative of the plant and wildlife communities of central New England. These types include wet meadow, shrub swamp, and bottomland forest.

- Wet Meadow

- Vegetation - Wet meadows are an early stage in wetland succession that develops on both floodplain and upland soils which are saturated during the spring growing season. The wet meadow community in the study area was dominated by emergent species including common horsetail (Equisetum arvense), jewelweed (Impatiens capensis), purple loosestrife (Lythrum salicaria), sensitive fern (Onoclea sensibilis) and hydrophytic grasses. Fringing this type in low density was green ash (Fraxinus pennsylvanica var. subintegerrima). Plant species richness in this type (10 species) was lower than in the other wetland and floodplain types sampled. This type is unstable, and over a period of perhaps 15-20 years, may be replaced by shrub swamp, the next successional stage, and/or the beginning stages of floodplain forest.

- Herpetofauna - The wet meadow habitats along the floodplain of the Merrimack River were sampled at the same time as the bird transects, from May 18 through May 21, 1982, and then again on September 14, 1982. Only the green frog (Rana clamitans) was observed to be present in the wet meadow areas.

- Avifauna - Two transects were sampled along the floodplain of the Merrimack River between May 18 and 21, as described in the methods (Terrestrial Ecology Appendix Section 8.33.2), between 05:13 and 07:55 EDT, during periods with no high wind or rain. Cloudy skies were encountered on one day, however the observer noted no reduction in the visibility or audibility of nearby birds, nor were activity levels of birds reduced.

  Those species found to have the highest densities were: song sparrow, yellow warbler, gray catbird, eastern kingbird, and red-winged blackbird.

  Species dependent upon this habitat or upon the adjacent open water included the common yellow-throat, yellow warbler, red-winged blackbird, mallard, herring gull, and belted kingfisher. Ring-necked pheasant was the only game species observed. In all, 34 species were observed in the wet meadow type.

- Mammals - The meadow vole and meadow jumping mouse were the only two species trapped in this habitat, representing 78% and 22% of the captures respectively. Meadow vole density was estimated to be 13.2/ha, whereas there were too few captures of jumping mice for a meaningful calculation of their density. Numbers caught and density estimates are presented in Terrestrial Ecology Appendix 8.33.2. Although none were caught, short-tailed shrews are found in this habitat. Tracks of cottontails (species unknown), domestic dogs, and cats were also observed in this habitat during the winter survey.

- Shrub Swamp

- Vegetation - Shrub swamps develop on both floodplain and upland sites inundated by standing water for a significant portion of the growing period. This type often succeeds the wet meadow type. Shrub swamps in the study area were dominated by silky dogwood (Cornus amomum), meadowsweet (Spiraea latifolia), arrow-wood (Viburnum recognitum), and green ash. Scattered throughout this type in lower numbers were trailing bramble (Rubus hispidus), choke cherry (Prunus virginiana), red maple (Acer rubrum), and willow (Salix sp.). There were 13 species of shrubs observed throughout this type. In the herbaceous layer, the predominant species were sensitive fern, hydrophytic grasses and royal fern (Osmunda regalis). In addition to these species, fewer numbers of other wetland herbs were found including marsh fern (Dryopteris thelypteris), purple loosestrife and sedge (Carex sp.). In all, 37 species were observed in this type. As with wet meadows, shrub swamps are unstable, however, the rate of change is much slower due to a more complex community structure. Shrub swamps are generally succeeded by wooded swamp or bottomland forest over a period of perhaps 60 years.

- Herpetofauna - The shrub swamp habitats along the floodplain of the Merrimack River were sampled at the same time as the bird transects, from May 18 through 21, 1982, and then again on September 14, 1982. Two species were noted in shrub swamp areas. American toad (Bufo americanus) and painted turtle (Chrysemys picta).

- Avifauna - Two transects were sampled through shrub swamps between May 18 and 21, as described in the methods (Appendix Section 8.33.2), between 04:55 and 07:39 EDT, during periods with no high wind or rain. Cloudy skies were encountered on one day, however, the observer noted no reduction in the visibility or audibility of nearby birds, nor were bird activity levels reduced. Those species found in the highest densities were: red-winged blackbird, common yellowthroat, yellow warbler, gray catbird, and American goldfinch. The only water dependent species observed were green heron, herring gull, belted kingfisher, and Louisiana waterthrush.

  Several species were observed which are highly typical of this habitat, including: tree swallow, yellow warbler, Louisiana waterthrush, and redwinged blackbird.

  In all, 32 species were observed in the shrub swamp type.

- Mammals - The meadow jumping mouse was the most abundant species at both the North Chelmsford and Methuen shrub swamp areas, representing 86% and 44% of all captures respectively. Their density was estimated to be 12.4/ha and 15.1/ha at the two sites. At the North Chelmsford site, meadow voles were the only other species caught and were probably attracted to the dense grass cover at the edge of the shrub swamp. The eastern chipmunk and white-footed mouse were also caught at the Methuen site. There were sufficient recaptures of white-footed mice to estimate their density at 3.8/ha. The presence of the chipmunk and white-footed mouse indicated a more mature vegetative community at the Methuen site than at the North Chelmsford area.

  Although none were caught, short-tailed shrews are frequently found in this habitat. The winter track surveys also indicated that cottontails (Sylvilagus sp.) are common in this type.

- Bottomland Forest

- Vegetation - Bottomland forest is adapted to the regular cycles of river flooding that occur during the spring growing season, and is the final stage in the succession of the floodplain community. There were three layers of vegetation in this type: the tree, shrub and herbaceous

layer. In the study area, the tree layer contained a predominance of green ash, American elm, and red maple, with fewer numbers of other tree species such as red oak (Quercus borealis), silver maple (Acer saccharinum), and paper birch (Betula papyrifera). In the shrub layer, saplings of green ash, Virginia creeper (Parthenocissus quinquefolia), silky dogwood and arrow-wood were predominant. Less frequently observed were elderberry (Sambucus canadensis), buckthorn (Rhamnus frangula) and saplings of American elm and buttonbush (Cephalanthus occidentalis). The dominant species in the herbaceous layer were sedge (Carex sp.) and sensitive fern with fewer numbers of other herbaceous species such as clearweed (Pilea pumila), Canada mayflower (Maianthemum canadense), ciliate loosestrife (Lysimachia ciliata) and jewelweed.

A total of 44 species were observed in this type. The bottomland forest type is stable, and will remain essentially unchanged in species composition and structure provided that flooding continues to occur during the spring growing season.

- Herpetofauna - The bottomland forest habitats along the floodplain of the Merrimack River were sampled at the same time as the bird transects, from May 18 through 21, and then again on September 14, 1982. Two species were noted in the bottomland forest areas: green frog (Rana clamitans) and spring peeper (Hyla crucifer).

- Avifauna - Two transects were sampled through bottomland forest habitats along the Merrimack floodplain between May 18 and 21, as described in the methods (Terrestrial Ecology Appendix Section 8.33.2), between 05:10 and 07:50 EDT, during periods with no high wind or rain. Cloudy skies were encountered on one day; however the observer noted no reduction in the visibility or audibility of nearby birds, nor were bird activity levels reduced.

  Much of this habitat lies close to the river in areas of medium to high population density. Consequently, although wild areas still exist, the invasion of urban-adapted avifauna is especially evident. Those species found to have the highest densities in this habitat were: common grackle, brown-headed cowbird, barn

swallow, European starling, and common yellowthroat.

Several species were observed which depend on the bottomland forest or the adjacent river: double-crested cormorant, great blue heron, mallard, and herring gull. The great blue heron was the only species noted on these transects of special concern in Massachusetts. Designated as "state rare", it was observed feeding along the edge of the bottomland forest but gave no indication of a nearby breeding location.
The ring-necked pheasant was the only upland game species observed.

Several species which are highly typical of this habitat were observed including black-billed cuckoo, common flicker, hairy woodpecker, blue jay, tufted titmouse, white-breasted nuthatch, American robin, wood thrush, veery, red-eyed and warbling vireos, black-throated green and Canada warblers, American redstart, common grackle, and rose-breasted grosbeak.

In all, 42 species were observed in the bottomland forests of the Merrimack River floodplain.

- Mammals - The eastern chipmunk and meadow jumping mouse were caught at both the Methuen and Andover locations for this type. In addition, white-footed mice were caught only at the Methuen location (north side of the river) while meadow voles were captured only at the Andover location (south side of the river). Captures were few in this habitat with density estimates calculated only for white-footed mice (16.4/ha) at the Methuen site and meadow jumping mice (1.5/ha) at the Andover site. Both gray squirrels and cottontails are common in this type as evidenced by the winter surveys. This habitat type is also ideally suited for racoons because of the close proximity of the river bank for foraging and the availability of den trees. Striped skunks and opossum are also expected to use this habitat.

- Threatened and Endangered Species - There is one historical record for each of two rare plant species in the study area. A rare species of sedge, Carex lenticularis var. blakei was reported in 1882 along the Merrimack River in Lowell and a bulrush, Scirpus fluviatilis, was recorded along the Merrimack River in Lawrence in 1877. The sedge is not currently verified

anywhere in the state, and there is only one current occurrence for the bulrush in Massachusetts (not in the study area) (Massachusetts Natural Heritage Program, 1982). The great blue heron (state rare) was observed in the study area during the 1982 field investigations. Mammals which have been listed from this region for special consideration include the southern bog lemming (state local) and the hoary bat (peripheral breeder) (Cardoza, 1982). Neither of these two species have been confirmed to be present in the study area.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 8.33.1, indicator species of plants, herpetofauna, birds and mammals were selected for the Merrimack River floodplain. The term "indicator species" as applied in this report denotes 1) species representative of floodplain and wetland habitats, and 2) species sensitive to the kinds of perturbations that may result from development of the Merrimack River alternative.

  The group of species selected is representative of the trophic levels and habitats within the study area and within potential project impact areas and will be used to assess impacts of water supply development on these habitats. These species are listed in Table 8.33-1.

  The indicator species were selected on the basis of seven criteria: these criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Available information on land use and population to the year 2020 is very limited, and the following analysis is the best possible given the limited data base. Based on the areawide 208 planning study (1977), and the MDC Water Supply Study and EIR, population is expected to increase significantly in the towns along the floodplain study area (except for Lawrence). The increase in population expected for most towns is over 10 percent per 5-year period.

Accompanying this population increase will be changes in land use patterns and cover types as open areas are developed and converted to urban areas. Wildlife diversity will progressively decline as urbanization continues and fewer species are able to adapt to the reduction in habitat quality and quantity. The wildlife most affected will be species that utilize floodplain communities as part of their habitat, but depend primarily upon cover in the adjacent uplands to fulfill most of their requirements.

TABLE 8.33-1. INDICATOR SPECIES SELECTED FOR THE MERRIMACK RIVER FLOODPLAIN ECOLOGY ASSESSMENT.

PLANTS	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Red oak	*Quercus borealis*	Softwood forest Hardwood forest	Primary producer
Beech	*Fagus grandifolia*	Hardwood forest	Primary producer
White pine	*Pinus strobus*	Softwood forest	Primary producer
Green ash	*Fraxinus subintegerima*	Bottomland forest	Primary producer
River birch	*Betula nigra*	Bottomland forest	Primary producer
Sensitive fern	*Onoclea sensibilis*	Wet meadow	Primary producer
Blue-joint grass	*Calamagrostis canadensis*	Shallow marsh	Primary producer
Water naiad	*Najas flexilis*	Shallow marsh	Primary producer
Sweetflag	*Acorus calamus*	Shallow marsh	Primary producer
Speckled alder	*Alnus rugosa*	Shrub swamp	Primary producer
Meadowsweet	*Spiraea latifolia*	Abandoned field	Primary producer
Gray birch	*Betula populifolia*	Shrubland	Primary producer
WILDLIFE			
American crow	*Corvus brachyrhynchos*	All habitats listed above	Detritivore
White-throated sparrow	*Zonotrichia albicollis*	Softwood forest Shrubland	Herbivore
Swamp sparrow	*Melospiza georgiana*	Shallow marsh Shrub swamp	Herbivore

TABLE 8.33-1. (Continued)

WILDLIFE	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
White-breasted nuthatch	Sitta carolinensis	Hardwood forest Bottomland forest	Primary carnivore
Chestnut-sided warbler	Dendroica pensylvanica	Abandoned field Shrubland	Primary carnivore
Red-tailed hawk	Buteo jamaicensis	Hardwood Forest Softwood forest Bottomland forest Shrub swamp Abandoned field Shrubland	Higher order carnivore
Barred owl	Strix varia	Softwood forest	Higher order carnivore
Great Blue Heron	Ardea herodias	Bottomland forest Wet meadow Shallow marsh Bog, Shrub swamp	Higher order carnivore
Gray squirrel	Sciurus carolinensis	Hardwood forest Bottomland forest	Herbivore
Beaver	Castor Canadensis	Bottomland forest	Herbivore
Meadow vole	Microtus pennsylvanicus	Wet meadow Bog, Shrub swamp Abandoned field Shrubland	Herbivore
Muskrat	Ondatra zibethica	Shallow marsh	Herbivore
Short-tailed shrew	Blarina brevicauda	All habitats listed under "Plants" except Shallow marsh, Bog	Primary carnivore
Pickerel frog	Rana palustris	Shallow marsh, Bog	Primary carnivore
Black rat snake	Elaphe obsoleta	Abandoned field Shrubland	Higher order carnivore

The wildlife that depend more completely upon riverine habitats will be less affected, since less development will take place in the vegetatively defined floodplain (that portion requiring yearly inundation during April and May) than in the bordering upland. In the floodplain, therefore, future conditions will be influenced primarily by natural plant community development processes. Since plant communities change relatively slowly, the differences in site vegetation and use by riverine wildlife between the three time periods considered below will be very slight.

- 1990 - The floodplain communities observed in the study area were wet meadow, shrub swamp and bottomland forest. Wet meadow is an early stage in the sequence of wetland and floodplain community development and by 1990 woody plants characteristic of shrub swamp, the next successional stage, may become established. Plant community composition and structure will remain predominantly wet meadow, although wildlife typically associated with shrub and sapling forms will also begin to utilize the meadow areas, increasing faunal diversity. Shrub swamps are also an early stage but due to a more complex community structure the rate of change is somewhat slower. It is unlikely that by 1990 this type will have changed sufficiently to significantly affect wildlife species composition, and the fauna will continue to consist of the species typically found in shrub swamp communities. Bottomland forest is the final stage in the development of the floodplain community. This type will remain essentially unchanged in terms of plant species composition provided that the annual flooding cycles continue unaltered, although tree growth will continue. Based on the slow rates of floodplain community change, wildlife use will not differ significantly from existing conditions.

- 2000 - By the year 2000, the wet meadows in the study area will most likely have become dominated by plant species typical of the shrub swamp type. This will provide habitat for wildlife species characteristic of shrub swamp communities. The shrub swamp will most likely not have changed sufficiently by 2000 to affect wildlife species composition, and the wildlife will remain typical of the species found in shrub swamp communities. The bottomland forest stands will remain essentially unchanged except for the growth of individual trees, and wildlife use patterns will not change greatly. With these minor exceptions future conditions along the floodplain study area will not differ substantially from existing conditions.

- 2020 - By 2020, saplings of tree species characteristic of bottomland forest may become established in the shrub swamp growth that will have taken over the wet meadow community by the year 2000. Due to the more complex community structure of shrub swamp compared to wet meadow the rate of change is generally slower and it is likely that shrub swamp will continue to be predominant in former wet meadow areas by 2020. It is unlikely that the establishment of the saplings will change community structure sufficiently to significantly affect wildlife species composition, and the fauna will remain typical of the species found in shrub swamp communities.

  In former shrub swamps, however, saplings typical of wooded swamp communities may have become established in sufficient numbers to encourage use by wildlife species typical of this successional stage, which will increase faunal diversity.

  The growth of the bottomland forest by 2020 may have changed the community structure sufficiently to increase shading which will reduce the density and alter the species composition of understory shrubs and herbs. Wildlife species composition may shift from ground nesting species to wildlife that favor large trees for nesting and/or feeding. With the above exceptions, future conditions along the floodplain by 2020 will not differ substantially from existing conditions.

8.33.2 Future Conditions With Alternative

Future conditions with this alternative are assessed both for the construction period and for three future time periods. Construction period impacts consider the immediate effects of vegetation removal, noise and disturbance on plant and wildlife communities, indicator species and species of special interest. Long-term impacts are changes in these communities and species resulting from changes in water quantity and quality. Construction period and long term project impacts on indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 8.33-2.

I. Short-Term Construction Period

- Impacts to Existing Conditions - A water treatment plant and shaft A will be constructed north of the Tyngsboro Bridge at a bend on the south side of the Merrimack River at the site of the intake structure to the MDC distribution system. A spoil pile and construction staging areas will require permanent

TABLE 8.33-2. SUMMARY OF IMPACTS OF THE PROPOSED MERRIMACK RIVER DIVERSION ON FLOODPLAIN PLANT AND WILDLIFE INDICATOR SPECIES.

	HABITAT TYPE								
Impact Categories:	Hard-wood Domin-ated Mixed Forest	Soft-wood Domin-ated Mixed Forest	Bot-tom Land Forest	Wet Mea-dow	Shal-low Marsh	Bog	Shrub Swamp	Abon-doned Field	Shrub Land
Erosion								X	
Water Quality									
Water Quantity									
Water Level			X	X			X		
Habitat Loss/ Change			X					X	
Displacement/ Disruption			X					X	
Entrainment/ Impingement									
Vegetation Composition Changes			X	X			X		

removal of 35 acres of mostly abandoned field/agricultural field, and temporary disturbance (during construction only) of another 4 acres. The plant indicator species that would be affected is meadowsweet. Among the wildlife indicator species affected would be a detritivore (American crow), two primary carnivores (chestnut-sided warbler and short-tailed shrew), an herbivore (meadow vole) and two higher order carnivores (red-tailed hawk and black rat snake) (Table 8.33-1). The crow and red-tailed hawk utilize this habitat type primarily for feeding whereas the chestnut-sided warbler, the two mammal species and the black rat snake fulfill both feeding and breeding requirements in or immediately bordering abandoned field/agricultural field.

Several hundred acres of the abandoned field/ agricultural field type, already disturbed by human use, also occurs adjacent to and in the general vicinity of the floodplain between the New Hampshire border and Tyngs Island. The loss of a small portion of this type from the vicinity of the plant site will be a minor impact to populations of meadowsweet and the scattered vegetative complex in the surrounding area. The loss of a small amount of this type is not expected to seriously impact the wildlife communities or populations of indicator species that utilize it since, as discussed above, agricultural field/ abandoned field is also well represented elsewhere in the vicinity of the floodplain. These other locations may also be expected to support populations of the above indicator species. Moreover, neither this type nor its associated indicator species are unusual or unique in the area.

These facilities would also encroach very slightly on a bordering patch of floodplain forest. Displacement/ disruption to the edge of the floodplain forest will not be of a magnitude to result in significant impacts to the plant community or its indicator species. Limited soil erosion will occur but erosion controls and revegetation measures will be instituted during construction, and the recovery of affected areas will be rapid. Effects of short-term erosion on aquatic communities and mitigation for this impact is discussed in the Aquatic Ecology Section (8.31).

- Construction Impacts - Aside from the immediate effect of actual removal, discussed under "Impacts to Existing Conditions", the only potential construction impact on vegetation will be erosion. If uncontrolled during and after construction, soil loss from the impacted areas and immediately adjacent areas could

bring about a loss in soil fertility, reducing the rate of regrowth and possibly affecting long term plant production. Soil transported to and desposited in other locations could have localized adverse affects on low growing vegetation in those plant communities. As discussed above, however, both short and long term erosion control and revegetation measures will be developed in order to reduce this impact to an absolute minimum (section 8.33.4).

The potential short-term impacts of the construction activities on wildlife include disturbance due to noise and the presence of humans, temporary loss of some habitats, direct mortality associated with land clearing and filling, and the effects of air emissions from the construction equipment.

Land clearing and construction activity in the project area is expected to generate noise in the 70-98 dBA range. Generally, impacts of noise on wildlife fall into three categories (Memphis State University, 1971): 1) interference with intra- and interspecific communication, 2) injury to the hearing apparatus, and 3) effects on the animal's neuro-endocrine system similar to stress. Most vertebrate species would instinctively move away from noise sources so as to avoid the latter two effects. Interference with communication primarily involves the masking of species-specific calls or other vocalizations used in courtship, territorial defense, parent-young interactions, or predator evasion. The chestnut-sided warbler and other song birds are the primary group which would be affected in the project area. Many amphibians (frogs and toads) also use auditory signals for communication, although this normally occurs in the evening or at night when construction activity will have ceased.

The land clearing and filling required for the project will result in the unavoidable mortality of a limited number of small mammals, reptiles and amphibians. Highly mobile species, including all birds and large mammals, will leave the area once the construction activities commence. Other species, such as the meadow vole, short-tailed shrew, black rat snake, and terrestrial amphibians will, however, seek refuge in underground burrows or other sheltered areas and perish. If construction takes place during the breeding season for birds (primarily spring and early summer), there will also be the unavoidable loss of all nests with eggs and young in the construction areas. Similarly, the litters of all breeding mammals will be lost.

Impacts associated with fugitive air emissions, such as dust and exhaust fumes from the construction equipment, will be very localized. As most vertebrate species will seek cover away from the construction activities, this impact is expected to be minimal. Insects and other invertebrates are more likely to be directly impacted, resulting in some secondary effect on wildlife higher in the food web which depend on them for food. As the area involved is relatively small, this impact is not considered significant.

II. Long Term - Changes in water level at a representative section of the Merrimack River floodplain (Terrestrial Ecology Appendix Figure 8.33-2) with the proposed transfers were determined using 50-year average flow data for April, May and June. April and May are the most important months from the standpoint of inundation requirements of the floodplain plant communities. Throughout much of the rest of the year, the water level is normally below at least part of the floodplain. Based on the 50-year flow record, flows during April and May will be sufficient for transfers more than 95 percent of the time, while maintaining the low flow requirement (6000 cfs in April and 4000 cfs in May). June is the month when impacts on river channel plants caused by a decrease in water level would be most likely to occur. Under normal conditions, the plants may be stressed by insufficient water for part of the month but not so much as to eliminate potential for project impact when flows were higher than the minimum requirement. Based on the 50-year flow record, June flows will be sufficient for withdrawal approximately 63 percent of the time, while maintaining the 4000 CFS low flow requirement. June, therefore, is a "worst-case", having the greatest number of days (19) that transfers can occur under early summer, low flow conditions.

Plant indicator species potentially affected by a reduction in water level are green ash, river birch, sensitive fern and speckled alder. The wildlife species potentially affected by changes in vegetation composition caused by a reduction in water level include a detritivare (American crow), four herbivores (gray squirrel, beaver, meadow-vole and swamp sparrow), two primary carnivores (white-breasted nuthatch and short-tailed shrew) and two higher order carnivores (red-tailed hawk and great blue heron) (Table 8.33-1). The white-breasted nuthatch, gray squirrel and beaver satisfy the majority of their life cycle requirements, including breeding, in the bottomland forest, whereas the swamp sparrow utilizes the shrub swamp types for feeding and breeding. The other indicator species utilize combinations of wet meadow, shrub swamp and bottomland forest habitats to fulfill life cycle requirements.

Calculations demonstrated that the net decrease in water level attributed to the proposed transfer to the MDC distribution system during April and May will be approximately 2 inches, resulting in a decrease of approximately 2 feet in the lateral extent of flooding on the north bank. This is likely to be the maximum decrease in flooded area within the 5 percent study area because the transect location chosen had one of the flattest profiles. A decrease of 2 feet in lateral flooding is within the range of yearly variation and will have no observable affect upon green ash, river birch, speckled alder, sensitive fern, or other floodplain vegetation because the accuracy with which the vegetatively defined floodplain (vegetative community consisting of greater than 50 percent hydrophytic species) can be delineated in the field is much less precise than this. This is because the floodplain/upland boundary is often indistinct, occurring within a transition zone; this zone is broad at cross sectional areas having a flat profile, narrowing at steeper cross sections.

If a decrease of 2 inches in water level across the floodplain were to have a long term effect on the rate or direction of floodplain community development resulting in changes in vegetation composition, such an effect would be imperceptible. Based on the above analysis differences in water level with and without the project are considered insignificant for the purposes of this analysis.

The calculations demonstrate that the net decrease in water level attributable to transfers in June will also be approximately 2 inches, resulting in a maximum decrease of approximately 2 feet in the lateral extent of flooding, which will expose part of the floodplain. However, at this point, the water level is still sufficient to fill the river above the top of the channel, and there will be no observable effect on river channel vegetation.

Since the vegetative communities and plant indicator species are not likely to change perceptibly as a result of the transfer, neither are wildlife feeding or breeding habitats. This being the case, both changes in water level and those caused by water level change are expected to have minimal impact on the indicator species and populations of other wildlife species. Field methods, cross section locations and flow/stage calculations are presented in Terrestrial Ecology Appendix 8.33.2.

- 1990 - Since changes in water quality (Section 8.21.2) and quantity are not expected to differ substantially from conditions projected without the alternative, changes in the floodplain plant and animal communities by 1990 will be as discussed in Section 8.33.1.II.

- 2000 - Because changes in water quality and quantity are not expected to occur as a result of project operation, changes in floodplain communities by the year 2000 will not differ from those described for "Future Conditions Without Alternative".

- 2020 - If the safe yield constraints do not change, water quantity and quality will not differ from conditions projected without the alternative. This being the case, development of the plant and wildlife communities of the wet meadow, shrub swamp and bottomland forest types by 2020 will not differ substantially from that expected without the project.

8.33.3 Significant Impacts

No significant short or long term impacts to floodplain or river channel plant or wildlife communities, indicator species or species of special interest are expected to occur as a result of the proposed transfer.

I. Measures of Significance - Existing water quality baselines were determined and projections with and without the project were made. Changes in water level relative to the floodplains and river channel due to the project were determined based on 50-year average flow data for April, May and June the most important times of the year with respect to floodplain and river channel inundation requirements. Vegetation and wildlife were identified and their uniqueness relative to the surrounding communities determined. Indicator species representative of floodplain communities which will respond to water level and water quality changes were selected (see "Task 4: Indicator Species Selection"). The uniqueness of the plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to changes in water level or quality were the measures used to judge the significance of project impacts.

II. Significant Impacts - Since no significant short or long term impacts on floodplain or river channel vegetation or wildlife are anticipated as a result of the proposed transfer, there are no significant impacts.

8.33.4 Mitigation/Enhancement Measures

Erosion control during construction will protect river channel vegetation from siltation.

8.34 TERRESTRIAL ECOLOGY OF THE MERRIMACK R.O.W.

An assessment of the vegetation, herpetofauna, avifauna and mammals of the Merrimack R.O.W. was conducted. The study area for this assessment included the R.O.W. from the proposed transfer in Lowell to the MDC distribution system near Boston.

8.34.1 Baseline Conditions

Assessments of the existing baseline, and baseline conditions projected to 1990, 2000 and 2020 without the project were made. Literature cited is listed in Terrestrial Ecology Appendix Section 8.34.3. Study methods, species lists and quantitative data are presented in Appendix 8.34.2.

I. Existing Conditions - In the following sections previous investigations applicable to the Merrimack Tunnel R.O.W. are presented by groups of biota, and the results of field investigations conducted in 1982 are discussed by vegetative community.

- Literature Surveys

  - Vegetation

    Regional Vegetation - The vegetation of the Merrimack Tunnel R.O.W. is part of the regional vegetation discussed in Section 8.33.1.

    R.O.W. Vegetation - No previous investigations of the vegetation of the Merrimack Tunnel R.O.W. are known to have been conducted.

  - Herpetofauna - No previous herpetological studies are known to have been conducted in the Merrimack R.O.W. corridor; however a list of the New England species having ranges that overlap the study area were obtained from Conant (1975), and Lazell (1972). The lists of state rare and local species were obtained from Blodget et al. (1982).

    The habitat and feeding information for this study was also obtained from the above sources, with additional information taken from the species accounts in Lazell (1976), Wright and Wright (1949 and 1957), Bishop (1941), and Carr (1952).

    The study area for this alternative lies in the coastal lowlands, well out of the ranges of many of the warm-climate herpetofauna. Several

southern species reach the northern limit of their ranges at this point, for example the Blanding's turtle (Emydoidea blandingi) and the box turtle (Terrapene carolina). Compared with the climate in the vicinity of the Connecticut and Millers/Tullys alternatives, the climate of the Merrimack R.O.W. corridor is somewhat less severe during winter due to the ameliorating influence of the nearby ocean water. Of the 36 species with ranges overlapping the study area, there are 7 turtles, 11 snakes, 8 salamanders, and 10 frogs.

- Avifauna - Information regarding breeding ranges of bird species was obtained from Peterson (1980), and from the Breeding Bird Atlas Survey conducted between 1974 and 1979 by the Massachusetts Audubon Society. Specific lists were compiled for this study area by carefully evaluating the latter source and including each species classified under "probable breeding record" status. The emphasis in evaluating this data was on including all possible species in the baseline species list for the study area.

  The Breeding Bird Atlas is compiled based on rectangular areas occupying one-sixth of a USGS Topographic map, and measuring about three miles on each side. Wherever the floodplain included such an area, the atlas list of breeding species was added to the study list.

  The avifauna of the Merrimack River R.O.W. corridor typically shows a mixture of several types of birds:

  1) water-dependent species including waterfowl, marsh and swamp birds, and gulls; some of these are primarily coastal species, venturing inland along rivers.

  2) northern species at the southern limit of their breeding ranges such as northern junco, white-throated sparrow, yellow-rumped and Canada warblers;

  3) species adapted to artificial food supplies such as house sparrows, pigeons, and starlings;

  4) wide-ranging resident species such as the woodpeckers, crows and jays, and titmice; and,

5) wide-ranging migrant species including most of the warblers, vireos, and fringilids (finches, sparrows, buntings, and grosbeaks).

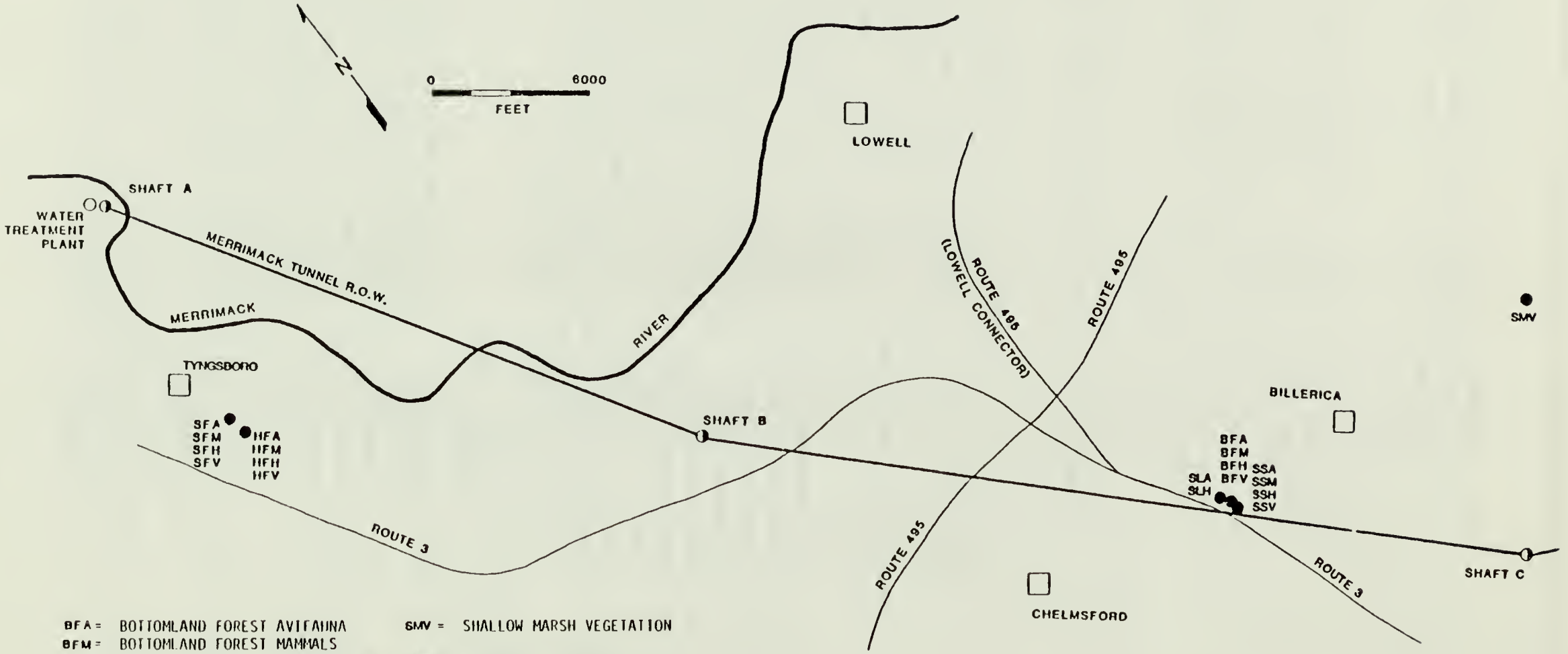
All these categories of birds are of concern in this study area, since construction may alter the ecology of any species. Species at the limit of their breeding ranges, however, are at particular risk, since it is very likely that they are operating near the limit of their niche tolerance, and are therefore more sensitive to many types of impacts.

- Mammals - Existing information on mammals for this study area is the same as that reviewed in Section 8.33 for the Merrimack River floodplain.

- Field Surveys - In the following subsections the results of field investigations at representative stands of all of the R.O.W. communities in the study area are discussed for vegetation, herpetofauna, avifauna and mammals. The locations of the study transects are shown in Figure 8.34-1. Where appropriate, the groups of biota are presented by plant successional stage beginning with the earliest stage and most primitive wildlife group. Complete species lists and data are presented in Terrestrial Ecology Appendix 8.34-2. Generally, the plants and wildlife occurring in the R.O.W. habitat types of the study area were representative of the types indigenous to central New England. The types found at the eight shaft and five spoil pile locations along the R.O.W. include:shallow marsh, shrub swamp, bottomland forest, shrubland, hardwood-dominated mixed forest and softwood-dominated mixed forest.

  - Shallow Marsh

  - Vegetation - The shallow marsh type is an early wetland successional stage that occurs on floodplain and upland soils that are flooded during spring and early summer. The marsh community in the study area included growths of shrub swamp species on the periphery and in scattered patches which consisted of rose (Rosa sp), sweet gale (Myrica gale), speckled alder (Alnus rugosa) and pink azalea (Rhododendron nudiflorum). The marsh proper was dominated by cattail (Typha latifolia) and purple loosestrife (Lythrum salicaria) with lower numbers of arrowhead (Sagittaria sp), pickerelweed (Pontederia cordata) and water hemlock (Cicuta



BFA = BOTTOMLAND FOREST AVIFAUNA
BFM = BOTTOMLAND FOREST MAMMALS
BFH = BOTTOMLAND FOREST HERPETOFAUNA
BFV = BOTTOMLAND FOREST VEGETATION

HFA = HARDWOOD FOREST AVIFAUNA
HFM = HARDWOOD FOREST MAMMALS
HFH = HARDWOOD FOREST HERPETOFAUNA
HFV = HARDWOOD FOREST VEGETATION

SFA = SOFTWOOD FOREST AVIFAUNA
SFM = SOFTWOOD FOREST MAMMALS
SFH = SOFTWOOD FOREST HERPETOFAUNA
SFV = SOFTWOOD FOREST VEGETATION

SMV = SHALLOW MARSH VEGETATION

SLA = SHRUBLAND AVIFAUNA
SLH = SHRUBLAND HERPETOFAUNA

SSA = SHRUB SWAMP AVIFAUNA
SSM = SHRUB SWAMP MAMMALS
SSH = SHRUB SWAMP HERPETOFAUNA
SSV = SHRUB SWAMP VEGETATION

Figure 8.34-1. Terrestrial Community Stations in the vicinity of the Merrimack Tunnel R.O.W. sampled by NAI in 1982.

bulbifera). A total of 15 species were observed in this type. Being an early stage in plant succession, this type is unstable and may be replaced by shrub swamp, the next successional stage, over a period of perhaps 15-20 years.

- Herpetofauna and Avifauna - The shallow marsh habitat was not sampled for birds or herps during the 1982 summer season because the representative location selected was not large enough to permit application of the sampling methods used to characterize these populations in other vegetative types. This does not constitute a significant gap in information required to assess project impacts because shallow marsh is only meagerly represented along the Merrimack R.O.W. and baseline conditions are primarily characterized by other vegetative types. Moreover, shallow marsh will not be impacted at any of the spoil pile or shaft locations.

- Mammals - There were no traps set in this habitat type because of its wetness. Meadow voles and meadow jumping mice are usually common along the marsh-wet meadow edge. White-footed mice and short-tailed shrews are also found along any wooded, upland border. Both the mink and raccoon commonly forage along the shorelines of marshes. The only true marsh inhabitant, however, is the muskrat whose populations reach their greatest density in cattail marshes.

- Shrub Swamp

- Vegetation - This type, a later successional stage than shallow marsh, develops in floodplain and in upland sites inundated by standing water for a significant part of the growing season. The Shrub Swamp community in the study area was dominated by saplings of red maple (Acer rubrum), with some speckled alder, buckthorn (Rhamnus frangula) and arrow-wood (Viburnum recognitum) also present. In the herbaceous layer the predominant species were marsh fern (Dryopteris thelypteris), skunk cabbage (Symplocarpus foetidus) and jewelweed (Impatiens capensis). Lower numbers of other species such as tussock sedge (Carex stricta), sensitive fern and fowl-meadow grass (Glyceria striata) were also observed. A total of 25 species were observed in this type. Over a period of perhaps 60 years this type may succeed to bottomland forest.

- Herpetofauna - The shrub swamp habitats along the Merrimack R.O.W. corridor were sampled at the same time as the bird transects, from June 9 through 12, 1982, and again on September 14, 1982. The only species observed in the shrub swamp community was the garter snake, (Thamnophis sirtalis).

- Avifauna - One transect was sampled through a shrub swamp in the R.O.W. corridor, between June 9 and 12, as described in the methods (Appendix 8.34.2). Little wind and clear to broken sky prevailed throughout this four-day sampling period.

  Those species found to have the highest densities were gray catbird, common yellowthroat, blue jay, swamp sparrow, and common grackle.

  Only two species were observed which are highly dependent on this habitat, red-winged blackbird and swamp sparrow.

  In all, 19 species were observed in the shrub swamp habitat of the Merrimack R.O.W..

- Mammals - Both the white-footed mouse and meadow vole were caught in this habitat type, representing 67% and 33% of all captures respectively. Numbers captured and density estimates for these species are presented in Terrestrial Ecology Appendix 8.34.2. Meadow voles were common near the shrub swamp edge where herbaceous plants were dominant. Although not observed, raccoons frequently forage in this habitat for amphibians and other food items. During the winter, cottontails utilize the abundant cover afforded by shrub swamps.

- Bottomland Forest

- Vegetation - The bottomland forest type is composed of the tree, shrub and herbaceous layers. In the study area the dominant species in the tree layer was red maple, with a few white pine (Pinus strobus) and elm (Ulmus Americana) scattered throughout the layer. The shrub layer contained a predominance of arrow-wood, with buckthorn and blackberry (Rubus spp.) less numerous. Also present throughout this layer, but in lower proportions, were scattered saplings and young shrubs of species such as white pine, poison sumac (Rhus vernix) and highbush blueberry

(Vaccinium corymbosum). There were 8 species of shrubs observed in this type. In the herbaceous layer the predominant species was jewelweed, with a few skunk cabbage, sedge (Carex sp) and sensitive fern found. A total of 20 species were observed in this type. Provided that spring flooding cycles continue unaltered, bottomland forest is a mature, stable type that will remain self perpetuating.

- Herpetofauna - The bottomland forest habitats along the Merrimack R.O.W. corridor were sampled at the same time as the bird transects, from June 9 through 12, 1982, and then again on September 14, 1982. No herpetofauna were observed during these periods in bottomland forest.

- Avifauna - One transect was sampled through a bottomland forest in the R.O.W. corridor between June 9 and 12, as described in the methods (Section 8.34.2) between 05:07 and 08:09 EDT. No adverse weather conditions were encountered during this four day sampling period, and there was little wind and clear to broken sky throughout.

  Those species found to have the highest densities were European starling, gray catbird, northern cardinal, brown-headed cowbird, and red-tailed hawk.

  Several species were observed which are highly dependent on this habitat, including red-tailed hawk, tree swallow, red-winged blackbird, and swamp sparrow.

  In all, 17 species were observed in the bottomland forest of the Merrimack R.O.W..

- Mammals - Only the white-footed mouse and southern red-backed vole were caught in this habitat type, with 60% and 40% of all captures respectively. The density of white-footed mice was estimated to be 4.5/ha; there were too few captures of voles for an estimate of their density. During the winter survey, gray squirrel, raccoon, and cottontail sign was commonly observed in this type. Other common species expected to utilize this habitat are the striped skunk and Virginia opossum.

- Shrubland

- Vegetation - Vegetation studies were not conducted because the only shrubland location in the R.O.W. was beneath a powerline. Since the powerline vegetation was regularly subjected to chemical spraying it was not considered a representative shrubland community from the standpoint of plant species composition.

- Herpetofauna - The shrubland habitats along the Merrimack R.O.W. corridor were sampled at the same time as the bird transects, from June 9 through 12, 1982, and then again on September 14, 1982. No herpetofauna were observed during these periods in the shrubland type.

- Avifauna - One transect was sampled through a powerline shrubland habitat between June 9 and 12, as described in the methods (Appendix Section 8.34.2), between 04:51 and 07:52 EDT. Although the vegetation beneath the powerline was maintained by chemical spraying, the shrubland was similar structurally to unsprayed shrublands, and was considered representative with respect to wildlife use. No adverse weather was encountered during these four days, with little wind and clear to broken sky throughout the sampling period.

  Those species found to have the highest densities were brown-headed cowbird, common yellow-throat, gray catbird, European starling, and red-winged blackbird.

  Wetland dependent species were evident due to nearby wetland habitats. These included: green heron, herring gull, tree swallow and swamp sparrow.

  Several species were observed which are typical of this habitat including eastern kingbird, blue jay, black-capped chickadee, tufted titmouse, gray catbird, yellow and chestnut-sided warblers, northern cardinal, and rufous-sided towhee.

  In all, 27 species were observed in the shrublands of the Merrimack R.O.W..

- Mammals - Three small mammal species were trapped in this habitat type. White-footed mice and meadow jumping mice each represented 44% of all captures, and eastern chipmunks represented 11%

of all captures. The occurrence of these species is indicative of the intermediate stage in development of this upland habitat. Eastern cottontails and white-tailed deer are also species that are expected to utilize this habitat.

- Hardwood-Dominated Mixed Forest

• Vegetation - The mixed forests are, by far, the most abundant types in the study area. The hardwood- dominated mixed forest type differs from the softwood-dominated mixed forest type only in having a tree layer dominated by a higher proportion of hardwood species. The mixed forest types are interspersed throughout the study area. The hardwood-dominated mixed forest contains a tree layer dominated by white oak (Quercus alba), red oak (Q. borealis), red maple and white pine. American elm and gray birch occurred in fewer numbers. In the shrub layer the predominant plant species were wintergreen (Gaultheria procumbens), partridge berry (Mitchella repens) and late sweet blueberry (Vaccinium angustifolium). Twenty-five other species were scattered throughout this layer in lower numbers, including saplings of the tree species. In the herbaceous layer the predominant species were starflower (Trientalis borealis), sedge and Canada mayflower (Maianthemum canadense). In addition to these species fewer numbers of other woodland herbs were found including ground pine (Lycopodium obscurum), sessile bellwort (Uvularia sessilifolia), wood anemone (Anemone quinquefolia) and wild sarsaparilla (Aralia nudicaulis). A total of 49 species were observed in this type. The mixed forest type is a climax community in this area, and, as the species composition of the shrub layer indicates, is in a stable, self-perpetuating state.

• Herpetofauna - The hardwood-dominated mixed forests along the Merrimack R.O.W. corridor were sampled at the same time as the bird transects, from June 9 through 12, 1982, and then on September 14, 1982. Species observed in hardwood-dominated mixed forest included: wood frog (Rana sylvatica), American toad (Bufo americanus), eastern ringneck snake (Diodophis punctatus edwardsi), and red-backed salamander (Plethodon cinereus).

- Avifauna - One transect was sampled through a hardwood-dominated mixed forest between June 9 and 12, as described in the methods, Appendix Section 8.34.2, between 04:50 and 07:48 EDT. No adverse weather conditions were encountered during this four day sampling, and there was little wind and clear to broken sky throughout the period.

  Those species found occurring in the highest densities were: rufous-sided towhee, black-capped chickadee, blue jay, wood thrush, and brown-headed cowbird.

  Several species were observed which are very typical of this habitat, including those species with the highest densities, listed above, and black-billed cuckoo, hairy woodpecker, American crow, tufted titmouse, brown creeper, ovenbird, scarlet tanager, and rose-breasted grosbeak.

  In all, 20 species were observed in the hardwood-dominated mixed forests of the Merrimack R.O.W..

- Mammals - Only the white-footed mouse was caught in this habitat type. The scarcity of species in the area trapped can probably be attributed to the relative paucity of shrub-layer vegetation and ground cover. Both chipmunks and gray squirrels are common in this habitat. Tracks of the latter species were observed during the winter survey. Raccoons also find den sites in this habitat, but frequently feed either in habitats such as croplands or along wetlands. This habitat was considered too mature to be suitable for white-tailed deer as there was very little browse available.

– Softwood-Dominated Mixed Forest

- Vegetation - This type differs from the preceeding type only in having a higher proportion of softwood species in the tree layer. In the tree layer the dominant species were white pine and red oak, with white oak, red maple and serviceberry (Amelanchier laevis) found in lower abundance. Predominant in the shrub layer were late sweet blueberry (Vaccinium angustifolium), white pine and red oak saplings and partridgeberry. Saplings of red maple, white oak, serviceberry and black cherry (Prunus serotina) and shrubs such as sheep laurel (Kalmia angustifolia), huckleberry (Gaylussacia sp.) and

hazlenut (Corylus americana) occurred in fewer numbers. The most abundant species in the herbaceous layer were ground pine and sedge, with other herbs including Canada mayflower, starflower and wild sarsaparilla occurring in lower numbers. There were 25 species observed in this type. As with the preceeding community, the softwood-dominated mixed forest is a stable, self perpetuating climax community in this area.

- Herpetofauna - The softwood-dominated mixed forests along the Merrimack R.O.W. corridor were sampled at the same time as the bird transects, from June 9 through 12, 1982, and then again on September 14, 1982. No herpetofaunal species were found.

- Avifauna - One transect was sampled through a softwood-dominated mixed forest between June 9 and 12, as described in the methods (Appendix Section 8.34.2), between 05:18 and 08:13 EDT. No adverse weather was encountered and there was little wind and clear to broken sky throughout the sampling period.

  Those species found to have the highest densities were herring gull, black-capped chickadee, rose-breasted grosbeak, blue jay, and scarlet tanager. The herring gulls were observed soaring over the forest. They were recorded as part of this habitat due to its location between the Merrimack River and a large landfill, which is frequented by gulls.

  The only species of special concern in Massachusetts was the Swainsons thrush, listed as a "state local" species, which was observed once on this transect. This should not be regarded as a possible breeding record, however, since this species is habitually a late migrant, frequently observed lingering and singing along the migration route. The breeding bird atlas contains no records of breeding Swainsons thrush for this corridor between 1974 and 1979.

  Omitting the herring gull, the most typical species observed included the remaining four listed above with the highest densities, plus eastern pewee, American crow, tufted titmouse, brown creeper, hermit thrush, ovenbird, and rufous-sided towhee.

In all, 19 species were observed in the softwood-dominated mixed forests of the Merrimack R.O.W..

- Mammals - As in the hardwood dominated forest, only one species, the white-footed mouse, was captured in this habitat. Red squirrels are a characteristic species of softwood forests but their populations vary in size. Young softwood growth also provides suitable winter cover for deer, protecting them from the wind and preventing snow accumulations. Snowshoe hares are also common in young softwood stands, which provide suitable protection from predators. During the winter survey, tree bark gnawed by porcupines was also noted.

- Threatened and Endangered Species -- There is one historical and one current record for a rare plant species in the study area, one historical and one current record for two rare salamander species and two current records for a rare amphipod species (Massachusetts Natural Heritage Program, 1982; D. Smith, 1982). The rare bur-reed, Sparganium minimum, was reported at Spot Pond in Stoneham in 1834, and in the Middlesex Fells Reservation in 1978. The spotted salamander (Ambystoma maculatum) and four-toed salamander (Hemidactylum scutatum) were recorded in Middlesex Fells Reservation in 1959 and 1920 respectively. Swainsons thrush, listed as state local, was observed in the study area during the 1982 field investigations.

  The lowland river amphipod, Crangonyx pseudogracilis, is composed of several genetically distinct forms or populations. Population B is known to occur only in a few small lowland seeps or runoff streams of the Merrimack and Mystic River watersheds. Population B specimens were collected in 1978 at Spot Pond Brook in Middlesex Fells Reservation and the Aberjona River.

- Selection of Indicator Species - From the inventory and analysis of baseline conditions presented in Section 8.34.1I, indicator species of plants, herpetofauna, birds and mammals were selected for the Merrimack R.O.W.. The term "indicator species" as applied in this report denotes 1) species representative of floodplain and wetland habitats, and 2) species sensitive to the kinds of perturbations that may result from development of the Merrimack Tunnel R.O.W..

  The group of species selected is representative of the trophic levels and habitats within the study area and

within potential project impact areas and will be used to assess impacts of water supply development on these habitats. The selection of species to serve as sensitive indicators of environmental change was based on analysis of candidate species sensitivity to the kinds of impacts discussed throughout Section 8.34.2. These species are listed in Table 8.34-1.

The indicator species were selected on the basis of seven criteria; the criteria and the selection process are presented in the report "Task 4: Indicator Species Selection".

II. Future Conditions Without Alternative - Available information on land use and population to the year 2020 is very limited, and the following analysis is the best possible given the limited data base. Based on the area wide 208 planning study (1977), and the MDC Water Supply Study and EIR, population is expected to increase significantly in the towns along the R.O.W. study area. The increase in population expected for most towns is greater than 10 percent per 5-year period.

Accompanying this population increase will be changes in land use patterns and cover types as open areas are developed and converted to urban areas. Wildlife diversity will progressively decline as urbanization continues and fewer species are able to adapt to the reduction in habitat quality and quantity. In the areas allowed to remain as open space, future conditions will be influenced primarily by natural plant community development processes. Since plant communities change relatively slowly, the differences in site vegetation between the three time periods considered below will be very slight.

- 1990 - The R.O.W. communities observed in the study area include shallow marsh, shrub swamp, bottomland forest, shrubland, hardwood-dominated mixed forest and softwood-dominated mixed forest. Conditions in the wet meadow, shrub swamp and bottomland forest types for 1990, 2000 and 2020 are discussed in Section 8.33.1II and the analysis is not repeated here. The shallow marsh and wet meadow types are very similar in structure and composition, and the discussion relevant to the latter applies equally to the former. Accordingly, the following discussion addresses conditions in the shrubland and two mixed forest types.

  The development pattern of the regional vegetation complex is one which culminates in a climax plant community dominated by oaks and pine. Due to the close functional and structural relationship of the

TABLE 8.34-1. INDICATOR SPECIES SELECTED FOR THE MERRIMACK TUNNEL R.O.W. ASSESSMENT.

PLANTS	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Red oak	Quercus borealis	Softwood forest Hardwood forest	Primary producer
Beech	Fagus grandifolia	Hardwood forest	Primary producer
White pine	Pinus strobus	Softwood forest	Primary producer
Green ash	Fraxinus subintegerima	Bottomland forest	Primary producer
Sensitive fern	Onoclea sensibilis	Wet meadow	Primary producer
Blue-joint grass	Calamagrostis canadensis	Shallow marsh	Primary producer
Water naiad	Najas flexilis	Shallow marsh	Primary producer
Sweetflag	Acorus calamus	Shallow marsh	Primary producer
Speckled alder	Alnus rugosa	Shrub swamp	Primary producer
Meadowsweet	Spiraea latifolia	Abandoned field	Primary producer
Gray birch	Betula populifolia	Shrubland	Primary producer
WILDLIFE			
American crow	Corvus brachyrhynchos	All habitats listed above	Detritivore
White-throated sparrow	Zonotrichia albicollis	Softwood forest Shrubland	Herbivore
Swamp sparrow	Melospiza georgiana	Shallow marsh Shrub swamp	Herbivore
White-breasted nuthatch	Sitta carolinensis	Hardwood forest Bottomland forest	Primary carnivore

TABLE 8.34-1. (Continued)

WILDLIFE	SCIENTIFIC NAME	HABITAT TYPE	TROPHIC LEVEL
Chestnut-sided warbler	Dendroica pensylvanica	Abandoned field Shrubland	Primary carnivore
Red-tailed hawk	Buteo jamaicensis	Hardwood Forest Softwood forest Bottomland forest Shrub swamp Abandoned field Shrubland	Higher order carnivore
Barred owl	Strix varia	Softwood forest	Higher order carnivore
Great Blue Heron	Ardea herodias	Bottomland forest Wet meadow Shallow marsh Bog, Shrub swamp	Higher order carnivore
Gray squirrel	Sciurus carolinensis	Hardwood forest Bottomland forest	Herbivore
Meadow vole	Microtus pennsylvanicus	Wet meadow Bog, Shrub swamp Abandoned field Shrubland	Herbivore
Muskrat	Ondatra zibethica	Shallow marsh	Herbivore
Short-tailed shrew	Blarina brevicauda	All habitats listed under "Plants" except Shallow marsh, Bog	Primary carnivore
Pickerel frog	Rana palustris	Shallow marsh, Bog	Primary carnivore
Black rat snake	Elaphe obsoleta	Abandoned field Shrubland	Higher order carnivore

R.O.W. vegetation to the regional complex, the sequences and rates of maturation can be assumed to be the same. The time required for a type such as shrubland to mature to a climax forest may be 60-80 years. Wildlife species composition will ultimately shift from edge and shrubland species to those favoring woodlands as the plant community matures. Mixed forests, on the other hand, which are already at or near the climax stage will change very slowly. Given the slow rate of plant community change, conditions in 1990 in undeveloped areas will differ only slightly from existing conditions. The minor changes that occur will be due to slight maturation of the shrubland type.

- 2000 - By 2000, the shrubland community will mature due to the growth of saplings and shrubs, however wildlife species composition will remain typical of the species found in shrubland. It is unlikely that the saplings of mixed forest species will have become sufficiently established by 2000 to alter community structure enough to affect wildlife species composition. The mixed forest types will change relatively little as a result of plant community development. Based on these observations, conditions by the year 2000 will not be substantially different from existing conditions.

- 2020 - By 2020, saplings of mixed forest tree species may become established in the shrubland type. At this stage, the community will be a young mixed forest and wildlife typically found in such habitats will also begin to utilize this type. The mixed forest type will remain essentially unchanged although tree growth will continue. If crown development increases shading to the understory and alters the composition and density of shrubs and herbs, wildlife species composition may shift from ground nesting species to those favoring large trees for nesting and/or feeding. Except for these natural developmental processes, conditions by the year 2020 will not be substantially different from existing conditions.

8.34.2 Future Conditions With Alternative

Future conditions with the project are assessed both for the short term construction period and long term. Construction period impacts address immediate effects of vegetation removal on plant and wildlife communities, indicator species and species of special interest (Impacts to Existing Conditions). Assessment of construction impacts also includes effects such as disturbance, noise and soil erosion (Construction Impacts). Future conditions

address impacts on baseline conditions projected to three future time periods, and consider changes in communities and indicator species brought about by the processes of stabilization and regrowth at each of the eight impacted areas along the R.O.W. Short term and long term project impacts on indicator species utilizing potentially affected habitats are summarized by impact category and habitat in the matrix in Table 8.34-2.

I. Short-term Construction Period

- Impacts to Existing Conditions - At each of the eight impact areas along the R.O.W., permanent and temporary features including spoil piles, shafts, roads, and construction staging areas will result in the permanent loss and/or temporary disturbance of vegetative cover. The regrowth at each of the areas will consist of earlier, less stable successional stages than presently exist (See II. Long-Term). The effect of this cover change, if any, will be assessed from the standpoint of impact to the vegetative and wildlife communities on the Merrimack R.O.W., and impact to the plant and animal indicator species selected to represent the communities in the vicinity of each of the eight impact areas.

  - First Spoil Pile (Water Treatment Plant) and Shaft A - Impacts at the first spoil pile and Shaft A were considered together with those of the immediately adjacent treatment plant in Section 8.33.2I under "Impacts to Existing Conditions".

  - Second Spoil Pile and Shaft B - At the second spoil pile location, just north of the intersection of Interstate 3 and Route 4 in Chelmsford, tunnel spoil and other structures will require permanent removal of 3 acres within a gravel pit. Temporary roads and construction staging areas will involve temporary disturbance of another 2 acres and may also border several small stands of the hardwood and softwood mixed forest types at the edges of the gravel pit.

    The plant indicator species at the edges of the hardwood and softwood mixed types potentially affected by these activities are red oak, white pine and beech. The wildlife indicator species potentially affected by habitat loss/change and displacement/disruption include a detritivore (American crow), two herbivores (gray squirrel and white-throated sparrow), two primary carnivores (white-breasted nuthatch and

TABLE 8.34-2. SUMMARY OF IMPACTS OF THE PROPOSED MERRIMACK R.O.W. ON TERRESTRIAL PLANT AND WILDLIFE INDICATOR SPECIES.

	HABITAT TYPE								
Impact Categories:	Hard-wood Domin-ated Mixed Forest	Soft-wood Domin-ated Mixed Forest	Bot-tom Land Forest	Wet Mea-dow	Shal-low Marsh	Bog	Shrub Swamp	Abon-doned Field	Shrub Land
Erosion	X	X						X	X
Water Quality									
Water Quantity									
Water Level									
Habitat Loss/ Change	X	X						X	X
Displacement/ Disruption	X	X						X	X
Entrainment/ Impingement									
Vegetation Composition Changes	X	X						X	X

short-tailed shrew) and two higher order carnivores (red-tailed hawk and barred owl) (Table 8.34-1). The white-breasted nuthatch and gray squirrel satisfy the majority of their life cycle requirements in the hardwood-dominated forest whereas the white-throated sparrow and barred owl fulfill their requirements in softwood-dominated forest. The crow, red-tailed hawk and short-tailed shrew utilize both habitat types.

The mixed forest types are well represented within a 2 mile radius of the site, and may be expected to contain habitat for the above indicator species. The impacts of loss of habitat necessary to fulfill life cycle requirements of plant and wildlife indicator species populations and communities will be insignificant. Displacement/disruption impacts will be temporary, the noise and disturbance occurring only during the construction period.

- Third Spoil Pile and Shaft C - The third spoil pile location, east of the Concord River in Billerica, also occurs primarily in a gravel pit, and will permanently impact a total of 35.5 acres; areas of abandoned field, shrubland and hardwood forest around the edges of the gravel pit may also be affected. Roads and construction staging areas will involve temporary disturbance of another 4 acres.

In addition to the indicator species that utilize the hardwood type discussed for the Second Spoil Pile, meadowsweet and gray birch are other plant indicator species potentially affected. Other wildlife species potentially affected are an herbivore (meadow vole) primary carnivore (chestnut-sided warbler) and a higher order carnivore (black rat snake) (Table 8.34-1). All three species utilize both the abandoned field and shrubland types to fulfill feeding, reproduction and other life cycle requirements. The abandoned field, shrubland and mixed forest types are well represented within a 2 mile radius of the site, and impacts of habitat loss on the plant and wildlife indicator species populations and communities will be minimal. Displacement/ disruption impacts on wildlife indicator species expected to utilize the area will also be minimal because the noise and disturbance will be confined to the construction period.

- Fourth Spoil Pile and Shaft D - Shaft D, just north of the intersection of a powerline and Gleason Road in Billerica, and the fourth spoil pile, just north of Cook Street, will permanently impact 3 acres, and temporarily disturb another 2 acres mostly within gravel pits. As with the last two locations, the roads and other temporary and permanent structures will also border or encroach very slightly upon adjacent areas of abandoned field and mixed forest.

  The plant and wildlife indicator species discussed in relation to the second and third spoil piles are the same species expected to be affected at the fourth spoil pile. The vegetative types at this location are well represented within a 2 mile radius of the site, and impacts of habitat loss on the indicator species populations and plant and wildlife communities are expected to be insignificant. Displacement and disruption of the wildlife indicator species would occur only during construction.

- Fifth Spoil Pile and Shaft E - Shaft E occurs in Woburn just south of Route 128, and will temporarily impact 4 acres of urban land. The fifth spoil pile, which will also include spoil from Shafts F, G, H and J, will permanently impact 26.5 acres, primarily within a large gravel pit. Plants and wildlife utilizing these sites are not dependent upon these habitats, and impacts of losses of urban structures and areas of gravel pit on the plant and wildlife communities and indicator species will be insubstantial.

- Shafts F and G - Shafts F and G are located on the east side of and immediately bordering Spot Pond in Stoneham. At this location the Spot Pond Pump Station, and other structures and facilities will permanently impact 3 acres in an urban park, and temporarily disturb another 4 acres. A stand of mixed forest, exceptional in the area because of the size of the trees, borders the park to the north and could be encroached upon if proper safeguards were not made part of the final design. Otherwise, no impacts to natural communities or indicator species are anticipated since the vegetative growth occurring in the park in the vicinity of the potential impact area is primarily of a cultivated and managed variety.

There is a historical record for the bur-reed (Sparganium minimum)(1834), a species of special concern in Massachusetts, at Spot Pond. Thorough searches of the vicinity of the potential disturbance area must be made to confirm the presence and assess the likelihood and extent of project impacts to this species.

Soil erosion during and after construction will be minimized by the implementation of a soil erosion control plan.

- Shaft H - The location of Shaft H in Middlesex Fells Reservation, will require permanent removal of 1 acre of hardwood dominated mixed forest and temporary disturbance of another 2 acres. The plant and wildlife indicator species potentially affected by proposed activities at this shaft location are the same as those discussed in relation to the hardwood forest at the second spoil pile location. As is true at other spoil locations, the hardwood forest type is well represented within a 2 mile radius of the site. The impacts of this small localized habitat loss on the plant and wildlife indicator species populations and communities associated with this type are expected to be insignificant.

There are records of occurrence for several species of special concern in Massachusetts. A current record (1978) for the bur-reed exists for the Middlesex Fells Reservation, as well as records for the spotted salamander (Ambystoma maculatum) (1959) and four-toed salamander (Hemidactylum scutatum) (1920). The proposed disturbance area is adjacent to a pond which is potential habitat for these three species. Specimens from a genetically distinct population of the lowland river amphipod (Crangonyx pseudogracilis) (Population B) were collected at Spot Pond Brook in the Middlesex Fells Reservation. In addition, the Swainsons thrush was observed in this area during the 1982 NAI field studies. Thorough searches of the vicinity of the potential disturbance area must be made to assess the likelihood and extent of project impacts to any of the above species.

A soil erosion control plan will be implemented during and after construction, such that any impacts to the pond due to sedimentation will be minimal and temporary.

- Shaft J - The location of Shaft J at MDC distribution shaft 9A in Medford, will permanently impact 0.5 acre and temporarily affect 1 acre of urban land. Plants and wildlife occurring at this site are urban species not dependent upon the habitats presently existing. The effects of permanent and temporary loss of urban habitat at this site on plant and wildlife communities and indicator species will be negligible.

- Construction Impacts - Impacts to vegetation and wildlife during construction, aside from the immediate affect of actual habitat removal, will be as discussed in Section 8.33.2I under "Construction Impacts."

II. Long-Term - This section assesses long term impacts of the project on the communities of plants and animals, and the indicator species occurring at the six (of the total eight) impact areas that are not completely urbanized. Following removal of the vegetative cover at these six areas, establishment of earlier, less stable successional stages will occur. These communities will mature over the three time periods considered below, following the same pattern as the regional complex which culminates in a climax community. Maturation will occur at a faster rate than the established communities now existing because plant community growth and development occur more rapidly in the earlier successional stages.

This difference in successional rate between future conditions with and without the project constitutes the major impact, except where species of special concern are involved. Whereas most of the indicator species now present may be expected to reoccur when the vegetation at the impact areas has attained a certain developmental stage, the conditions appropriate for species of special interest are often not as readily definable, and may or may not appear again at the revegetated and recolonized site. Differences in site vegetation and wildlife use between the three time periods with the project will be greater than the differences without the project.

- 1990 - Immediately following construction activities a seeding of grasses and legumes will be established for erosion control and site stabilization in all disturbed areas. Depending upon soil characteristics, the initial seeding on the upland sites can be expected to be supplemented by a natural cover of various forbs and grasses by 1990.

  Among the wildlife initially colonizing this early successional stage will be the meadow vole,

shorttailed shrew, and chestnut-sided warbler, all indicator species. Crows, red-tailed hawk and black rat snake will also readily utilize these areas in fulfilling life cycle requirements.

- 2000 - After the initial several years of site stabilization and early succession, the plant communities in the disturbed areas can be expected to be colonized by "pioneer" shrubs and saplings characteristic of early, unstable successional stages. Such early established woody species would include sweet fern, trembling aspen, gray birch (an indicator species) and pin cherry; on sites formerly forested, root suckers and sprouts would in addition, give rise to saplings of overstory species such as red oak (an indicator species). Over time, the shrubs and saplings will predominate as the impacted areas succeed from an herb dominated community to a shrubland. Depending on their height and steepness, plant community succession on the spoil piles may occur much more slowly due to the steepness and suboptimal physical and chemical soil conditions; moreover, the slope conditions could prevent placement of organic soils, liming and fertilizing to aid plant growth.

  The newly established shrubland communities will provide habitat for several of the wildlife indicator species: short-tailed shrew, meadow vole, American crow, chestnut-sided warbler, red-tailed hawk, and black rat snake. Meadow vole populations will be relatively low since this habitat will rapidly become too mature for this species. However, short-tailed shrews as well as more woodland species like the white-footed mouse will be common. The shrub-thicket habitat will also provide ideal cover for nesting chestnut-sided warblers and other old-field and shrubland species, such as the white-eyed vireo, blue-winged warbler, common yellowthroat, prairie warbler, and song sparrow. Both crows and the red-tailed hawk will use this habitat for feeding and perching. As the vegetation continues to mature, its suitability for the black rat snake, primarily a woodland species, will similarly increase.

- 2020 - After a period of more than thirty years have elapsed since the construction phase, the shrub/sapling community that has become established on the upland sites at the impacted areas will have a component of young tree species characteristics of the oak-pine climax forest. Among these species red oak and white pine, both indicator species, would be expected to predominate as the community develops,

along with smaller proportions of white oak, hemlock and red maple. Over time, most of the disturbed areas will succeed to the climax forest stage, having characteristics similar to the same communities in undisturbed areas. As noted above, plant communities on the spoil piles will develop much more slowly due to suboptimal physical and chemical soil conditions, perhaps never succeeding to a true climax stage.

As the vegetation matures towards a young forest habitat, species such as the meadow vole and chestnut-sided warbler will disappear. White-footed mice will be common, along with several new species of breeding birds including the gray catbird, brown thrasher, and rufous-sided towhee. White-throated sparrows (an indicator species) will be abundant in those brushy areas dominated by softwoods. Some mature forest bird species, like the black-capped chickadee and blue jay, may also begin breeding in this habitat.

8.34.3 Significant Impacts

Potentially significant impacts to vegetation and wildlife of the Merrimack R.O.W. would be disturbance or removal of a plant species, two amphibian species and one amphipod species, all of special concern, in the vicinity of shaft locations F/G and H, at Spot Pond and Middlesex Fells Reservation respectively, during construction.

I. Measures of Significance - The acreage involved at each of the eight impact areas in the Merrimack R.O.W. for spoil piles, shafts, roads, construction staging areas, and other temporary and permanent facilities was determined. The vegetation and wildlife at representative areas of each vegetative community in the R.O.W. were identified and their uniqueness relative to the surrounding communities determined. Indicator species representative of each community which will respond to perturbations resulting from the project were selected (see "Task 4: Indicator Species Selection)". The uniqueness of the impacted plant and wildlife communities, presence of species of special concern, and sensitivity of these biota and any indicator species to project impacts formed the basis for judging the relative significance of the impacts.

II. Significant Impacts

1. The project may impact a bur-reed species, the spotted salamander, four-toed salamander, and the lowland river amphipod, all of special concern in Massachusetts, in the vicinity of Spot Pond and the Middlesex Fells Reservation.

8.34.4 Mitigation/Enhancement Measures

1. Erosion control and revegetation will occur during, and following, construction and site stabilization.

2. Construction activities should be timed to avoid the spring and early summer breeding period of most wildlife species.

3. An adequate buffer between project facilities, open water bodies, and wetlands should be provided for their protection.

8.40 AIR QUALITY

8.40.1 Baseline Conditions

I. Existing Conditions - Despite significant progress by the Commonwealth of Massachusetts in enhancing air quality, violations of the State and National Ambient Air Quality Standards (NAAQS), except for sulfur dioxide and nitrogen dioxide, have continued to occur in Massachusetts. Specifically, the entire state has been designated as nonattainment of the standards for ozone-hydrocarbons while selected communities in the state have been designated as non-attainment for carbon monoxide and the secondary standard for total suspended particulates. None of these latter communities are in the Merrimack River Alternative project area.

Air quality is monitored in the Commonwealth by the Massachusetts Air Sampling Network operated by the Department of Environmental Quality Engineering (DEQE). The results of air sampling measurements are reported in annual summaries published by DEQE [1-5]. Table 8.40-1 presents air sampling data reported for the DEQE stations located in Woburn and Tewksbury which are the stations closest to the Merrimack River Alternative. The measurements at these sites, however, may be used only to a limited extent to extrapolate existing conditions along the project corridor.

Given the regional nature of photochemical oxidant reactions and transport, it is most likely that ozone levels in this corridor are also exceeding standards. The level of total suspended particulates, however, is strongly influenced by local sources. This is evidenced by the Woburn monitoring station which is located in a suburban/commercial area and does not indicate standards violations. Because the new facilities associated with this alternative are not located near a major emission source it is unlikely that total suspended particulate standards are being exceeded in the project area.

Ambient concentrations of carbon monoxide are also strongly influenced by local sources, particularly heavily travelled streets and roads. Again, the rural/suburban character of the project area mitigates against carbon monoxide standards violations.

II. Future Conditions Without Alternative - The exceedance of National Ambient Air Quality Standards (NAAQS) is not unique to Massachusetts but is a condition which is present in many parts of the country. Accordingly, the 1977 Amend-

Table 8.40-1 Annual Summary of Air Quality Data

Total Suspended Particulates (ugm/m3)

Site	Year	Annual Geom. Mean	Max. 24-Hour Obs.	2nd Max. 24-Hour Obs.	# of Obs. Above 260	# of Obs. Above 150
Woburn	1978	44	121	95	0	0
Woburn	1979	46	123	108	0	1
Woburn	1980	52	135	103	0	0
Woburn	1981	43	85	77	0	1
Woburn	1982	41	95	95	0	0

Ozone (ugm/m3)

Site	Year	Max. 1-Hour Obs.	2nd Max. 1-Hour Obs.	3rd Max. 1-Hour Obs.	# of Obs. Above 235
Tewksbury	1980	323	274	227	6

ments to the Clean Air Act require all states to prepare State Implementation Plans (SIPs) for attainment of standards and submit them for review and approval by the U.S. EPA. These plans must demonstrate attainment of the NAAQS as expeditiously as practicable, but no later than the end of 1982 (or the end of 1987 for areas with serious ozone and/or carbon monoxide problems).

On December 31, 1978 the Governor of Massachusetts and on May 16, 1979, the Acting Commissioner of DEQE submitted revisions to the Massachusetts SIP designed to attain the NAAQS for carbon monoxide and ozone. However, the projections presented in these plans showed that attainment by the end of 1982 was not possible despite the implementation of all reasonably available control measures and that December 31, 1987 is the most expeditious attainment date. Extension of the date for attainment until 1987 has received EPA approval.

- 1990 - By the year 1990, the emissions from virtually every vehicle on the road will be controlled under the present schedule of Federal regulations on motor vehicle emissions. Virtually every vehicle also will require the use of unleaded gasoline. In addition, the Massachusetts motor vehicle exhaust emission inspection program is designed to maintain the performance of the vehicle emission control systems. Therefore, implementation of the revised state plan should result in air quality by 1990 which is consistent with present standards in all parts of the Commonwealth, including the communities affected by the Merrimack River Alternative.

  Current legislation mandates a periodic review of present standards in light of new scientific data for the purpose of promulgating revised or new standards. Plans are presently underway to modify the standard for total suspended particulates by promulgating a new standard for inhalable size particulates (particles 10 microns or smaller). This standard may become extant by 1990 and thereby affect a change in air quality levels from those presently considered acceptable.

  Future plans also include establishing new air quality standards for selected toxic substances. Up to 100 such substances may be listed by the year 1990.

- 2000 - In the absence of new legislation mandating stricter standards, compliance with present air quality standards should be maintained in this time period. Pressures from increased population in the communities affected by the Merrimack River Alternative may result

in additional atmospheric pollutant burdens. Existing Prevention of Significant Deterioration regulations place some limits on the growth of pollutant emissions.

Air quality standards may be established for toxic substances in addition to the initial list of approximately 100.

- 2020 - Continued increases in the population of the communities along the Merrimack River Alternative corridor may result in additional pollutant emissions.

8.40.2 Future Conditions With Alternative

I. Short-term Construction Period - The construction of new facilities required for implementation of this alternative have the potential to affect ambient air quality in several ways, including: (1) exhaust emissions from construction vehicles and equipment, (2) fugitive dust from construction vehicle traffic on unpaved roads, (3) fugitive dust from construction activities, and (4) fugitive dust from wind erosion of exposed land surface.

The principal contaminants emitted by heavy duty construction equipment are carbon monoxide, unburned and partially burned hydrocarbons, oxides of nitrogen and particulate matter. The particulate matter in exhaust emissions consists of both inorganic and organic compounds of high molecular weight. Table 8.40-2 presents emission factors published by the U.S. EPA [6] for various types of heavy duty construction equipment of both diesel powered and gasoline powered likely to be employed. Total emissions will depend on the number of units and the hours of operation for each type equipment. Because this information is not available for the Merrimack River Alternative, total emissions from this equipment cannot be estimated at this time.

Fugitive dust will be generated by vehicle movement during construction on unpaved roads and other exposed surfaces involving pulverization and abrasion of the surface materials by the vehicles' wheels followed by entrainment of the dust particles by turbulent air currents. The rate of emission varies with average vehicle speed, vehicle mix, surface texture and surface moisture. The major mass fraction of the particles are relatively large and tend to settle out within a short distance from the source.

Another potential source of fugitive dust arises when land is cleared permitting wind erosion of bare ground. The rate of emission varies with soil texture (specifically the silt content) and soil moisture.

The major new facilities required for implementation of this

Table 8.40-2 Heavy-Duty Construction Equipment Exhaust Emission Factors

Equipment Class	Carbon Monoxide (grams/hour)	Hydrocarbons (grams/hour)	Nitrogen Oxides (grams/hour)	Particulates (grams/hour)
Heavy-duty equipment Gasoline-powered				
Wheeled tractor	4320	227.5*	195	10.9
Wheeled loader	7060	318.9*	235	13.5
Heavy-duty equipment Diesel-powered				
Tracklaying tractor	175	50.1	665	50.7
Wheeled tractor	973	67.2	451	61.5
Wheeled dozer	335	106	2290	75
Wheeled loader	251	84.7	1090	77.9
Tracklaying loader	72.5	14.5	265	26.4
Off-highway truck	610	198	3460	116

*Includes evaporative and crankcase hydrocarbon emissions

alternative consist of constructing the water treatment plant and tunnel, pumping stations, laying pipelines, digging shafts and outlet structures. Fugitive dust emissions can arise from soil handling operations including land clearing, blasting, excavation, backfill, etc. Estimates of the volume of material moved, land temporarily disturbed, and the associated fugitive dust emissions are presented in Table 8.40-3. Without implementing effective control measures, the largest potential for fugitive dust emissions is associated with the spoil piles. The major mass fraction of these particles are relatively large and tend to settle out within a short distance from the source. The remaining smaller dust particles travel further downwind and generally are considered to be the more hazardous because they tend to be inhalable.

The second largest potential source of fugitive dust is associated with erosion of soil from land cleared for the water treatment plant site and from easements for laydown, roads, and work area. The worst case estimate shown in Table 8.40-3 is based on the assumption that half this land area is bare during the full 30-month construction period projected for completion of the project.

Without additional information and modeling analysis, it is not possible to project whether this alternative will result in local violations of NAAQS during this time period.

II. Long-term - The principal long-term impact from the Merrimack River Alternative arises from the continued energy consumption required to operate the system. Projected annual power consumption for this alternative is 84,462 mw-hr. This impact is an indirect one because the on-site electric power demand is generated at an off-site facility.

Electricity is generated by fossil-fuel power plants, nuclear power plants and hydroelectric power plants. Because the mix of electric generating plants supplying electrical power to operate the facilities associated with this alternative cannot be predicted, worst case emission conditions have been evaluated. Table 8.40-4 presents calculated annual emissions on the assumption that the power is generated by coal-fired or oil-fired units burning fuel containing the maximum sulfur content presently allowable under Massachusetts regulations.

For the same reason that the level of emissions cannot be uniquely determined, the location of these emission sources cannot be predicted. Consequently, the impact on local air quality cannot be estimated for this alternative.

- 1990 - The indirect source of gaseous and particulate emissions described above can be expected to continue

Table 8.40-3 Estimates of Fugitive Dust Emissions from Construction*

Activity		Volume Earth Moved (cu yds)	Fugitive Dust (tons)
Total all Spoil Piles		1,000,000	2,000
Land Temporarily Disturbed:			
Treatment plant site	35 acres		630
Easements	19 acres		342
		Total	2,972

*Before the application of control measures.

Table 8.40-4 Estimated Annual Power Plant Emissions From Electric Energy Demand

Coal-fired	Coal[1] (tons)	Sulfur Oxides (tons)	Carbon Monoxide (tons)	Hydro-carbons (tons)	Nitrogen Oxides (tons)	Particu-lates[2] (tons)
	42,230	1,263	21	6.3	377	82
Oil-fired	**Residual Oil[3] (bbl)**					
	153,115	1,125	16	2.5	339	80

[1]Assumes 1 lb coal input per Kw-hr output.

[2]Maximum emission rate of 3.9 lbs per ton of coal fired.

[3]Assumes 0.6 lb residual oil input per Kw-hr output.

to be present in this time period. The specific mix of power plant fuels used to generate the electrical energy demand for this alternative will dictate the additional pollutant burden.

- 2000 - Because of a continuing demand for electrical power for this alternative, the indirect source of gaseous and particulate emissions described above can be expected to continue to be present.

- 2020 - Although the demand for electrical power for this alternative will continue, the significant changes in fuel use patterns predicted for this era, particularly a reduction in the consumption of fossil fuels, would lower the potential for power plant pollutant emissions.

8.40.3 Significant Impacts

I. Measures of Significance - National Ambient Air Quality Standards for six pollutants were promulgated by the EPA on April 13, 1971. These pollutants are sulfur oxides, nitrogen oxides, carbon monoxide, photochemical oxidants, hydrocarbons, and total suspended particulates. A national ambient air quality standard for lead was promulgated on October 4, 1978, and the photochemical oxidant standard revised to an ozone standard on February 8, 1979. On January 5, 1983 the EPA revoked the standards for hydrocarbons. These national standards are minimums that all states are required to adopt. The primary standards, listed in Table 8.40-5, are intended to protect the public health, while the secondary standards are intended to protect the public welfare from any known or anticipated adverse effects. The table shows that the primary and secondary standards for those pollutants which are largely transportation related prescribe the same levels. Emissions from transportation sources are not expected to be a major factor in this alternative except from heavy duty construction equipment.

II. Significant Impacts - Increased emission of air pollutants over those presently occurring without the alternative can be expected as a consequence of implementing the Merrimack River Alternative. The principal short-term increase can be expected in the form of fugitive dust arising during the construction of the additional facilities required. Local violations of particulate standards could occur due to fugitive dust associated with construction activities unless control measures, such as those described below, are enforced. Additional emissions of carbon monoxide, nitrogen oxides, hydrocarbons and particulates also can be expected from the exhausts of the construction equipment used. The likelihood of violations of carbon monoxide or nitrogen

Table 8.40-5 Massachusetts and National Ambient Air Quality Standards

Pollutant	Averaging Interval[1]	Primary Standard (uqm/m3)	Secondary Standard (uqm/m3)
Sulfur Dioxide	Annual	80	--
	24-hr	365	--
	3-hr	--	1,300
Total Suspended Particulates	Annual	75[2]	60[2,3]
	24-hr	260	150
Nitrogen Dioxide	Annual	100	100
	1-hr[4]	320	--
Carbon Monoxide	8-hr	10[5]	10[5]
	1-hr	40[5]	40[5]
Ozone	1-hr[6]	235	235
Lead	3-mo[7]	1.5	1.5

[1]Standards other than those based on annual arithmetic means or annual geometric means are not to be exceeded more than once per year.

[2]Annual geometric mean.

[3]To be used as a guide for assessing implementation plans to achieve the 24-hour standard.

[4]DEQE guideline applicable only to major nitrogen oxide sources.

[5]Values shown are in units of mg/m3.

[6]Standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above standard is equal to or less than one.

[7]Maximum arithmetic mean averaged over a calendar year.

oxide standards cannot be estimated with the data available at this time.

Any effects from increased hydrocarbon emissions from construction equipment on ambient ozone levels would probably not be evident within the local communities, but would be manifest along downwind trajectories. Identification of the location and extent of these impacts requires additional highly complex modeling analysis.

Long term impacts on air quality can be expected to arise from the combustion products of fossil fuels burned at off-site generating stations to supply the electrical power demands of the new diversion facilities. The significance of this impact cannot be evaluated due to the uncertainty of the location and mix of power plant fuel consumption.

8.40.4 Mitigating/Enhancement Measures

The potential increases in air pollutant emissions can be mitigated by the application of a variety of control techniques. Control of fugitive dust is specifically required under Massachusetts regulation 310 CMR 7.09. Common non-chemical control techniques for unpaved roads include watering and traffic control. Watering can reduce emissions by 40-50 percent, but may require frequent retreatment during certain seasons to be effective. Spoil piles in particular require treatment to minimize wind erosion. All trucks should be hosed and washed clean of mud and dirt clinging to the wheels and exterior body surfaces to prevent mud and dust from being carried onto paved roads.

Reduction in the exhaust emissions from trucks and other heavy equipment can be achieved by restricting idling when these units are not in use.

Reductions in long-term emissions could be achieved through the implementation of energy conservation measures.

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8.41 NOISE

Operational noise levels of the Merrimack River Alternative are not expected to exceed ambient noise levels at existing noise sensitive receptors near the water treatment plant and the Spot Pond pumping facility if adequate noise control measures are implemented. Sludge removal trucks may generate noise impacts in noise sensitive areas along the haul route. During portions of the approximately 2½ year construction period, high levels of noise and vibrations are unavoidable in the vicinity of the nine shafts and the Spot Pond pumping facility. Tunneling activity is expected to be barely perceptible in houses within a few hundred yards of the tunnel, which is designed to lie 400 to 650 ft. below grade.

8.41.1 Baseline Conditions

I. Existing Conditions - The areas potentially affected by operational facility noise are undeveloped land between the Merrimack River and an operating railroad line with existing residential land use over 1000 ft. from the water treatment plant location and the New England Memorial Hospital in Stoneham, 500 to 1000 ft. from the Spot Pond facility site. Ambient daytime noise levels (L_{90}, i.e., the noise level exceeded 90 percent of the time) near the water treatment plant are estimated to lie between 25 and 35 dB(A) while the area around the hospital in Stoneham is extimated to have ambient levels of 30 to 45 dB(A).[1] Nighttime ambient noise is typically 5 to 10 dB lower for such low population density areas. At the water treatment plant area, existing noise sources include the Boston and Maine railroad and the more distant Middlesex Road, a local arterial highway. In Stoneham, Woodland Road, a moderately utilized roadway carrying noncommercial traffic is located between Spot Pond and the hospital.

II. Future Conditions Without Alternative - Modest increases in automobile traffic and possible increased freight train traffic are likely, although the noise level in decibels, being a logarithmic quantity, will not change significantly unless traffic increases amount to at least 20 to 30 percent of the existing conditions.

- 1990 - Existing ambient noise conditions will probably prevail.

- 2000 - Existing noise conditions will remain in effect unless population density changes occur or major noise producing facilities are constructed. Enforcement of noise emissions regulations for trucks, aircraft,

trains and other transportation methods could reduce ambient noise levels, despite increased traffic.

- 2020 - Noise conditions will probably be similar to those reached in 2000 unless further population density changes occur or major noise generating facilities are added.

8.41.2 Future Conditions With Alternative

I. Short-Term Construction Period - Construction of the nine shafts slated to occur over a nine month period with perhaps three shafts being worked on at a given time is expected to generate the considerable noise and some ground vibrations, mainly due to blasting in the vicinity of the shafts. In addition, trucks hauling excavated materials to nearby spoil piles will generate noise along routes which may normally not see much truck traffic. Boring of the deep tunnel is not expected to generate more than barely perceptible ground transmitted low frequency rumblings in houses located over or near the tunnel route. The boring machines should pass any given location in a matter of about a week. Depending on the strata encountered, the upper part of the shafts would be dug with mechanical earth moving equipment, such as hydraulic backhoes and graders.[2] In bedrock, material would be removed by the drill and blast method. Current blasting techniques employ time delayed charges which not only lead to more efficient rock removal but also lower peak ground motions and audible noise by stretching the explosion over a period of several seconds or more.[3] Safe distances of residential structures from near surface blasting is generally taken as[4]

$$d = 50\ W^{2/3}$$

where W is the explosive charge in pounds and d the distance in feet. For example, a 10 lb. charge may cause structural damage out to about 230 ft., while a 100 lb. charge requires a distance of at least 1000 ft. to avoid damage potential. This criterion indicates that sequentially fired small charges are much more desirable when blasting shafts near residential structures. From the topographic mass included in Bechtel Drawings SK-M-001 through SK-M-004, all shaft locations except D appear to be well over 500 ft. from current residential land use or in industrial areas. Shaft location D, north of Pinehurst, appears to be the closest to existing residential land use, possibly less than 500 ft. Construction of the Spot Pond pumping facility will involve extensive blasting. Being fairly near a hospital the work at this site will need to be carried out with extra care to limit ground transmitted vibrations and airborne noise.

The above ground facilities at Spot Pond, the water treatment plant, and the intake structure and raw water pumping facilities will be constructed with conventional construction equipment. Means of controlling noise from construction equipment are well know. Warning residents of unusual sporadic noises or ground vibrations due to blasting is generally accepted practice. In situations where a potentially severe impact is expected, the noisy activity may need to be scheduled to occur only during weekday daytime periods.

II. Long-Term - Operation of the water treatment plant and pumping station are not expected to generate significant noise or vibrations as long as suitable enclosures and other noise control measures are provided. Although the plan is to increase the capacity of the whole system in stages to match demand, the difference between the first and third stages in term of overall equipment noise is only 1.5 dB, a barely noticeable difference. The noise assessment of the fixed equipment is therefore based on the maximum capacity of the equipment.

The major noise generators include various pumps with up to 2900 horsepower motors, sludge centrifuges, sludge pumps and ventilation fans for the Spot Pond pump cavern. Estimates of noise from these facilities have been made and compared to estimated ambient noise at the nearest noise sensitive receptor lot lines or building facades, as appropriate.[5] Pump noise is based on motor horsepower, which in turn is based on flow capacity and total dynamic head.[6] Fan noise is estimated using generic procedures. In all cases, the equipment is located indoors and a noise reduction value of 25 dB(A) is applied. Ventilation openings and especially the outside air intake and discharge openings of the Spot Pond fans should be provided with suitable commercially available sound attenuators.

There is no available information on the noise of the air backwash equipment. The fact that the compressed air is discharged under water and its energy is largely expended pushing the debris laden water away from the screen means that relatively little noise is likely to be generated above the water.

Without noise control provisions, the estimated A-weighted noise level of the four main pumps at Spot Pond in the pump cavern is over 100 dB(A). Outdoors this noise is attenuated by the passage through the shaft, the topside building envelope, and distance to a level of about 35 dB(A) at 500 ft.

Untreated, the three ventilation fans at Spot Pond are expected to generate high discharge and intake noise

levels. However, if equipped with suitable sound attenuators the fan noise at 500 ft. is not expected to exceed 40 dB(A) or 34 dB(A) at 1000 ft.

The combined major equipment at the Tyngsborough water treatment plant is estimated to generate noise levels in the range of 40 to 45 dB(A) at 500 ft. The equipment is assumed to be installed in buildings with closed windows and suitably sound attenuated ventilation openings.

The estimated 25 truckloads of sludge to be transported off-site could lead to a noise impact in quiet residential areas along the haul route. Individual dump trucks at 30 mph produce noise levels of about 80 dB(A) at 50 ft and 74 dB(A) at 100 ft.[7] For example, up to 10 trucks per hour may pass a given observer during periods of peak activity. The corresponding equivalent hourly noise energy level would be 60 dB(A) at 50 ft and 57 dB(A) at 100 ft. Such values would probably exceed the daytime ambient noise in some residential areas more than 10 dB. Although the measure of significance utilized is normally applied only to fixed facilities, the truck operations are the same each day and therefore they represent an identifiable noise source. The noise from the sludge removal process including on-site equipment should be investigated in more detail if this alternative is selected.

8.41.3 Significant Impacts

I. Measures of Significance - Noise emissions from facilities should not exceed ambient noise at affected receivers by more than 10 dB.[8] The reference ambient noise conditions are the local ambient noise levels at the closest noise sensitive land use boundary measured prior to the facility preliminary design phase.

II. Significant Impacts - The noise generated by the fixed equipment of the water diversion facilities is not expected to be significant. To achieve this condition, some need of noise control measures described below is anticipated because of the large size of the pumping and ventilating equipment involved. Sludge removal may constitute a significant impact.

8.41.4 Mitigation/Enhancement Measures

Noise from fixed operational water treatment equipment could be reduced, if found necessary in the future, by various basic noise control methods including:

- Acoustical treatment of enclosures.
- Double glazing of large windows.

- Relocating louvers, or generally open windows to face away from noise sensitive areas.
- Sound attenuators installed in ventilation openings.
- Barriers placed between noisy outdoor equipment and noise sensitive areas.

Sludge handling equipment should be selected or modified to operate quietly and haul routes should be selected to avoid quiet residential areas and other noise sensitive receptors. Truck speed may need to be reduced in quiet areas. Trucks could also be monitored for noise output to identify trucks with faulty mufflers or other noise generating components.

If necessary, construction noise can be controlled by contract specifications requiring properly muffled engines and limiting hours of operation to normal weekday daytime periods. Use of explosives in inhabited areas required signals to alert people prior to firing and may also warrant preconstruction surveys of buildings to determine existing cracks and settlement.

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8.50 LAND USE

8.50.1 Baseline Conditions

I. Existing Conditions - Facilities for this alternative will be located in the towns of Tyngsborough, Chelmsford, Billerica, Burlington, Wilmington, Woburn, Winchester, Stoneham, Medford, and Malden. Existing land use in these towns (based on the MacConnell land classification information - 1971) is summarized in the following table. Undeveloped land is defined as the total acres of land in the forest and agriculture categories. The existing land use conditions in the potential service area communities are described in the technical appendix report: Task 4: No Action Assessment Report; this information is used to assess indirect impacts.

Table 8.50-1: Existing Land Use

TOWN	FOREST	WETLND	AGRI	URBAN	OPEN & PUBLIC	MINING & WASTE	OUTDR RECRTN	TOTAL ACRES
Billerica	11743 53%	873 5%	1571 9%	4759 29%	367 2%	165 1%	162 1%	19640
Burlington	2638 35%	126 2%	424 5%	4460 51%	375 5%	100 1%	88 1%	8211
Chelmsford	6158 40%	870 6%	1954 13%	5663 37%	253 2%	193 1%	113 1%	15204
Malden	440 13%	30 1%	52 2%	2294 70%	288 9%	52 2%	96 3%	3252
Medford	1485 26%	436 7%	88 2%	3022 54%	390 7%	26 1%	201 4%	5648
Stoneham	1667 38%	452 10%	191 4%	1668 40%	144 3%	4 1%	206 5%	4332
Tyngsborough	7753 70%	1031 9%	931 8%	1048 9%	75 1%	159 1%	188 2%	11185
Wilmington	5176 46%	493 5%	679 6%	4007 37%	214 2%	378 3%	129 1%	11076
Winchester	1233 30%	219 5%	105 3%	2156 54%	209 5%	0 0	138 3%	4060
Woburn	2386 29%	475 6%	868 11%	3768 45%	497 6%	195 2%	92 1%	8281

- Recreation. The existing recreational facilities and activities are discussed on a regional basis in the land use section of the report: Task 4: No Action. This baseline recreational information is based on the "Statewide Comprehensive Outdoor Recreation Plan (SCORP)" published in 1976 by the Department of Environmental Management; this report established seven planning regions and surveyed recreational facilities across the state. The communities affected by the Merrimack River Alternative are included in the data for Region IV of the SCORP Report.

  One public recreational area will be affected by the location of facilities for the Merrimack River alternative. The three shafts in Stoneham are located within the Middlesex Fells Reservation. The Middlesex Fells is managed by the MDC and consists of 3270 acres of wooded land and water located in the five communities of Malden, Medford, Melrose, Stoneham, and Winchester. The reservoirs within the Fells total some 650 acres of water and 30 miles of shoreline. Three reservoirs within the Reservation; North, Middle, and South Reservoirs, provide water to the Town of Winchester, and the land around these reservoirs is owned by the town.

  Active and passive recreation is available within the Reservation. In addition to hiking trails, picnicking areas and observation towers, there is a swimming pool, natural and rink ice skating, the Stone Memorial Zoo and shoreline fishing. Fishing is permitted in Spot Pond Reservoir, Fellsmere Pond and Dark Hollow Pond.

II. Future Conditions Without Alternative - The Merrimack Alternative passes through communities that vary considerably in their degree of urban development. Those inner suburbs (Malden, Medford, Stoneham, Winchester, and Woburn) experienced slow growth over the past thirty years and will change very little during the planning period because of the maturity and stability of the community development and the lack of available land for additional development. Four more suburban communities (Billerica, Burlington, Chelmsford, and Wilmington) have experienced considerable development over the past thirty years, and while they will continue to grow over the planning period, it will probably not be as rapid in the future. These communities have probably past their most rapid growth period, and their future slower growth will not be substantially different in pattern from that described above in Existing Conditions. As the least urban community, Tyngsborough will probably experience the most significant change in its land use pattern, since it is

expected to grow substantially over the planning period and has a large amount of undeveloped land. The future land use distribution in the potential service area communities is discussed in the land use section of the Task 4: No Action Assessment Report. Woburn and Tyngsborough are the two communities within the Merrimack Alternative included in that discussion. Both communities are projected to have an adequate amount of undeveloped land to accomodate the amount of development projected during the planning period.

8.50.2 Future Conditions With Alternative

I. Short-term Construction Period - There would be construction period land use impacts from those facilities that require the temporary use of land not acquired in fee simple. The Merrimack River Alternative would require temporary easements over a total of seventeen acres of land for construction access roads and contractor work areas. It is assumed that the cost of the easement, when privately-owned land is involved, would reflect the degree of disruption/inconvenience to the landowner.

While it has not been quantified at this time, there will be a short-term traffic impact from the tunnel construction. Trucks will have to carry the tunnel spoils from the shafts along the tunnel right-of-way to the spoil piles. In all cases, the spoil piles are not located adjacent to the shaft and therefore there will be some traffic impact. For Shafts D, E, F, G, H, and J, the spoil piles are located some distance away from the shafts because of the residential development or public open space surrounding the shafts.

II. Long-term

- Direct Land Use Issues. Direct land use issues would result from the land required to construct the necessary facilities and from permanent easements required for access to facilities. No permanent easements would be required for the Merrimack River Alternative.

  The Merrimack River Alternative would require the acquisition of 103 acres of privately-owned land. In addition, a sludge disposal landfill will require 150 acres of privately-owned land, but the site of this facility has not been identified as part of this study. The facilities necessary for the Merrimack River Alternative are located in the towns of Tyngsborough, Chelmsford, Billerica, Wilmington, Woburn, Stoneham and Malden. The intake structure, water treatment plant site and Shaft A area are located in Tyngsborough and involves 35 acres of land

that abuts the river and is currently in active agricultural use. The amount of land to be acquired represents .403 percent of the undeveloped land in Tyngsborough. Shaft B requires .5 acre of land in Chelmsford, plus 2.5 acres for the spoil pile. The spoil pile is a large mound of excavated soil and rock, a few feet higher than the surrounding area and would be replanted with grass and low shrubs. The spoil pile area is currently an abandoned, partially revegetated gravel pit, adjacent to some industrial development off Westford Street. The amount of land to be acquired represents .037 percent of the undeveloped land in Chelmsford. Billerica is the location of Shafts C and D. Shaft C required .5 acre for the shaft and 35 acres for the spoil pile. This partially wooded, undeveloped land is adjacent to the Concord River and abuts existing residential development. The shaft and spoils area at Shaft D involve .5 acre and 2.5 acres, respectively. The shaft area is an undeveloped, abandoned gravel pit, with the spoil pile located adjacent to the Shawsheen Technical School off Aldrich Road in an active gravel pit. The amount of land to be acquired represents .289 percent of the undeveloped land in Billerica. The facilities of Shaft E are located in two communities; the shaft site is in Woburn and the spoil pile is in Wilmington. The shaft site involves .5 acre of undeveloped land near an industrial park and is adjacent to the Aberjona River. The spoil pile involves 26 acres of undeveloped land and is a partially wooded gravel pit in Maple Meadow. The amount of land to be acquired represents .015 and .444 percent of the undeveloped land in Woburn and Wilmington, respectively.

Shafts F and G involve three acres of land, with Shaft H involving .5 acre of land. Shafts F and G, the Spot Pond pump station facilities and Shaft H are located within the boundaries of the Middlesex Fells Reservation, managed by the MDC, and will not have any land use impacts. Shaft J is located in a fully-developed urban neighborhood and would involve considerable disruption to the area during the construction of the shaft. One acre of land will be involved in Shaft J, but no additional land will have to be acquired for the shaft.

- Indirect Land Use Issues. The minor direct land use impacts discussed above will not result in significant indirect land use impacts. The safe yield of the Merrimack Alternative was designed to 120 MGD in 2020 which would adequately supply the projected total needs of the system and therefore would have no effect

on local growth or development patterns. The potential future development and the availability of suitable land to accommodate this growth is discussed in Task 4: No Action Assessment Report.

- Competing Water Users. In the Planning Area Report, it was determined that for the Merrimack River Alternative, the communities along the river including the towns from Tyngsborough to Haverhill would be possible competing users. This includes the communities of Tyngsborough, Lowell, Dracut, Methuen, Haverhill, Chelmsford, Tewksbury, Andover, Lawrence and North Andover. The communities of Andover, Lawrence and Methuen currently use the Merrimack River as a source of their water supply. Based on the water supply data reported to the Division of Water Supply in the Department of Environmental Management (1982) and population projection from the regional planning agencies, the Lawrence/Methuen system is projected to experience a water supply deficit during the planning period. Similarly, the Town of North Andover is projected to experience a local water supply deficit.

- Recreation Issues. The shafts located within the Middlesex Fells Reservation are located on the shoreline of Spot Pond and Fells Reservoir. Shafts F and G are located off Woodland Road on Spot Pond. Shaft F does involve some above-ground facilities, while Shafts G and H do not have facilites other than the pumphouses, and all together would involve approximately one acre. Due to the location of these facilities at existing reservoir sites, there would be no impact to recreation within the Reservation. The total amount of land involved is .03 percent of the land in the Reservation.

- Traffic Issues. Traffic impacts would result from vehicles travelling to and from the treatment plant in Tyngsborough. Since chemical deliveries are planned from a rail spur, there would be little, if any, truck traffic. Chlorine tank cars would make deliveries on probably a monthly basis. Sludge removal would involve approximately 25 dump trucks per day for six days per week, which would be a substantial increase in truck traffic. The plant would involve approximately 45-50 employees which would represent a substantial amount of traffic. Access would be near the junction of Route 113 and 3A and would be along residential road. The impacts on this residential area would be significant. During the construction period for Shaft J, there would be substantial truck traffic in the densely developed residential neighborhood.

8.50.3 Significant Impacts

I. Measures of Significance - The method for determining the significance of the land use and recreational impacts is discussed in the Assessment and Selection Criteria Appendix.

II. Significant Impacts - The direct land use impacts possible under the Merrimack River Alternative are significant due to the truck traffic at the water treatment plant. Indirect land use impacts would not be significant. Recreational impacts resulting from these alternatives also would not be significant.

8.50.4 Mitigation/Enhancement Measures

Additional analysis will determine whether the spoils sites of Shafts C and E would require an Order of Condition under Chapter 131A of the Massachusetts Wetlands Act. Further study will attempt to site the spoil piles in order to minimize any impacts on the wetlands.

8.60 SOCIO-ECONOMIC IMPACTS

The Merrimack River alternative provides an additional 120 MGD to the safe yield of the MDC water supply system at a total capital cost of $494 million. If this were to be constructed in three stages, the total capital cost would be $501 million with associated yields of: 86 MGD in 1990; 104 MGD in 2006; 120 MGD in 2013. On the basis of this examination, the socio-economic impacts associated with this alternative are expected to be minor except associated modest employment implications and at the local level during construction. Three categories of direct socio-economic impacts were examined to enable consistent comparison with other alternatives: direct employment, direct costs, and indirect and induced employment.

8.60.1 Baseline Conditions

I. Existing Conditions - The socio-economic baseline was profiled for the MDC potential service area including 44 current user communities and 13 potential future user communities in the Task 4: No Action Assessment Report.

II. Future Conditions Without Alternative - Key socio-economic characteristics were profiled for the planning area communities. Forecasts were prepared for milestone years during the planning period:

	1980	1990	2000	2020
Current User Population	2,455,417	2,264,430	2,443,193	2,605,579
Potential Future User Population	244,332	257,897	312,339	340,949
Current User Households	783,605	835,351	945,106	1,014,534
Potential Future User Households	68,963	83,137	105,363	116,514
Current User Employment	1,277,215	1,443,276	1,547,125	1,836,037
Potential Future User Employment	114,551	137,010	152,008	179,621

In addition, the MDC wholesale water rates and present retail water rates in individual planning area communities

were inventoried. The MDC wholesale water rate in 1983 was $240 per million gallons. The MDC wholesale rate was raised slightly in early 1984 to $245 per million gallons. Community water rates were obtained directly from the communities during the Summer and Fall of 1982 and reflect the levels and structures in place at that time. In the period since the passage of Proposition 2½, many Massachusetts communities have increased their water rates by up to 100 percent to reflect the "true cost" of delivering that service. When community rate data were collected, 10 MDC communities had increased water rates to fully recover operating costs. Under the baseline forecasts, it is assumed that by 1990 all communities will be charging rates at the full-cost recovery level, as permitted under Proposition 2½; these levels are equivalent to about $1.00 per hundred cubic feet of $1,337 per million gallons. (For a more detailed discussion of rates and water pricing, see Task 4: No Action Assessment Report and Section 3.23 of the Demand Management Report.)

8.60.2 Future Conditions With Alternative

The following types of employment impacts were considered for both the short and long term: direct employment impacts include employment which occurs as a direct result of the construction/installation, operation and maintenance of a new alternative, in this case, construction and operation. Indirect and induced employment impacts include employment associated with purchases of materials or services for the alternative and other employment occurring as a result of stimulated economic activity.

I. Short-term Construction Period - This alternative involves construction of a tunnel and supporting transfer facilities, pipeline and treatment systems to divert water using gravity flow from the Merrimack River. As summarized in Table 8.60-1, the short term employment impacts are moderately significant during the course of construction. Direct employment impacts associated with design and construction of the tunnels, pipelines and other components of the facilities are equivalent to 3,790 to 3,840 person years through the construction period in the Merrimack River alternative, the higher level associated with construction in one phase. Depending on the extent to which construction materials and services are purchased from within the region, indirect and induced employment associated with construction may be as high at 5,570 to 5,650 person years for the Merrimack alternative. This total impact, in either option, is equivalent to roughly 0.5 percent of planning area employment in 1990.

II. Long-term - A modest staff is required to operate the facilities under the Merrimack alternative, resulting in

TABLE 8.60-1

SUMMARY OF IMPACTS ASSOCIATED WITH
MERRIMACK RIVER ALTERNATIVES

Employment Impacts	Project Constructed In One Phase	Project Constructed In Three Phases
- Construction		
(person years during the period of construction)		
-- Direct	3,840	3,790
-- Indirect/Induced	5,650	5,570
- Long Term		
(average annual person years)		
-- Direct	90	74
-- Indirect	168	137

long-term direct employment impacts. These are estimated to be equivalent to about 74-90 person years, annually, again with the higher level associated with construction in one phase. The indirect and induced employment impacts are also expected to be modest--equivalent to about 137 to 168 person years, annually.

In addition, the following cost impacts were considered: Direct cost impacts include the changed costs of water supply associated with implementation of an alternative to the MDC, to the local water department and to individual rate payers.

The Merrimack River alternative provides the MDC with an additional 120 MGD of safe yield at a net present value cost of $567 per million gallons as summarized in Table 8.60-2. If construction of the alternative is phased, as noted above, then the net present value is $498 per million gallons. The net present value of each alternative has been estimated for purposes of comparing alternatives. If the marginal annual cost of amortized capital, operations and maintenance per million gallon is used as a basis comparison, the marginal cost would average $874 per million gallon in the years 1990 through 1994 (or 357 percent of the present wholesale rate) and $296 per million gallon in the years 2010 through 2014 (or 121 percent of the present wholesale rate), if the project is completed in one phase. If the project is completed in three phases, the marginal cost would average $1,041 per million gallon in the early years and $333 per million gallon in later years, or 285 percent and 136 percent of the wholesale rate, respectively.

If the cost of the alternative is then passed directly on to consumers by local water departments, and assuming that most communities charge water rates equivalent to the baseline of $1,337 per million gallons, then the cost impact of the Merrimack Alternative will be the additional wholesale cost passed-on directly to consumers. If the cost of one-phased construction is spread across all MDC users, the marginal annualized cost of amortized capital, operations and maintenance would result in a wholesale rate increase of $250 per million gallons or 102 percent in the early years (1990-1994) and about $85 per million gallons or 35 percent in the later years (2010-2014). If constructed in three phases the equivalent rate impacts would be $232 per million gallon, or 95 percent in early years and $89 per million gallon, or 36 percent in later years. The percentage retail cost impact for consumers will be roughly one-fifth of the wholesale cost impact since the wholesale rate is typically 18 percent of so of current retail rates. The equivalent impact on retail rates, then, is approximately 17 to 18 percent in the early

TABLE 8.60-2

SUMMARY OF COST IMPLICATIONS
ASSOCIATED WITH THE MERRIMACK RIVER

Cost Impacts	Project Constructed In One Phase	Project Constructed In Three Phases
- Additional Safe Yield.		
-- 1990 through 2004	120 MGD	86 MGD
-- 2105 through 2012	120 MGD	103 MGD
-- 2013 through 2020	120 MGD	120 MGD
- Net Present Value Per Million Gallons	$ 567	$ 498
- Average annual amortized capital, operation, and maintenance costs		
-- Early years (1990-1994)	$ 874/MG	$ 1,041/MG
-- Later years (2010-2014)	$ 296/MG	$ 333/MG
- Equivalent rate impacts spread over current MDC users		
-- Early years (1990-1994)	$ 250/MG	$ 232/MG
-- Wholesale rate impact	102%	95%
-- Retail rate impact	18%	17%
-- Later years (2010-2014)	$ 85/MG	$ 89/MG
-- Wholesale rate impact	35%	36%
-- Retail rate impact	6%	7%

years (1990-1994) and 6 to 7 percent in the later years (2010-2014).

This cost assessment assumes that the increased MDC capacity will be fully utilized, that is, that consumption will increase from 300 to 420 MGD under the one-phase construction option, and in the three-phase option from 300 to: 386 MGD in years 1990 through 2004; 403 MGD in years 2005 through 2012; and 420 MGD in years, 2013 through 2020.

Because of the relative inelasticity of the demand for water in response to changes in price, the direct cost impact to consumers associated with this alternative is anticipated to be minor to insignificant. This increase is less than the anticipated rate of inflation over a five-year period, and will therefore have a minimal to negligible affect on users.

8.60.3 Significant Impacts

I. Measures of Significance - Significant employment impacts at the community level are those involving direct employment greater than 100, and at the regional level, direct employment greater than 500. Significant cost impacts are anticipated to be equivalent to water rate increases exceeding double the rate of inflation over a five year period.

II. Significant Impacts - The only significant impacts associated with this alternative occur during the construction period, when direct employment at both the local and regional levels exceed the measures noted above. The direct cost impacts are modest to minor.

8.70 SIGNIFICANT CULTURAL RESOURCES

8.70.1 Baseline Conditions

I. Existing Conditions The project area for the Merrimack Alternative is located in the lowland plains of eastern Massachusetts. Documented prehistoric occupation and utilization of this area dates back to as early as the Paleo Indian Period (ca. 12,000 - 9,000 years ago), and spans the entire range of cultural periods currently recognized in prehistoric New England. Major concentrations of prehistoric sites in the region occur along the Concord, Shawsheen, and Merrimack Rivers, and around ponds near these major streams (MHC Files). Isolated sites have also been noted in upland areas away from these bodies of water; such sites probably represent areas of limited resource exploitation and had only occasional occupation. The major site locations in this region have thus far been associated with the larger streams, have a slope of less than 3 percent, and are on arable floodplain soils (MHC 1979:90-91).

Historical settlement in the Merrimack River Valley and coastal lowlands consisted initially of small agricultural communities located along the principal transportation corridors. Small industrial centers later developed along the Merrimack River, particularly where water power could be made useful. Portions of the towns located away from the river remained agricultural throughout the historical period. The development of Lowell as a major industrial center during the early 19th century resulted in a concentration of population in that area.

At the present time, no prehistoric or historical sites are recorded within the impact area of the proposed facilities for the Merrimack River Alternative.

II. Future Conditions Without Alternative Without a full evaluation of the location and condition of all potentially significant cultural resources at the proposed facility sites for the Merrimack Alternative, an adequate assessment of future impacts without the alternative is not possible.

Apart from the adverse effects of development or other land modifications, significant impacts upon existing cultural resources are not likely to occur.

8.70.2 Future Conditions With Alternative

I. Short-term Construction Period A number of facilities proposed for the Merrimack River Alternative will have a potential adverse impact on cultural resources. These include the construction shafts and their spoil piles; the water treatment plant at Tyngsborough; and related access roads, laydown areas, and work areas. The proposed tunnel from the Tyngsborough intake facility to Spot Pond will not disturb cultural resources because surface disruption during the tunnel construction will be limited to the shaft sites.

The construction of facilities for the Merrimack River Alternative will result in two types of impact on cultural resources that may exist at the facility sites. Primary archaeological impacts involve extensive or total disruption of the ground surface, resulting in the destruction of cultural resources. Secondary archaeological impacts involve intermittent or sporadic disruption or compaction of the ground surface, resulting in limited disturbance to, but not complete destruction of, existing cultural resources. In general, construction at the various facility sites will include both primary and secondary impacts in differing amounts.

The principal construction-related impacts of the Merrimack River Alternative are listed below by facility, total acreage of disturbance, and type of anticipated archaeological impact.

- Shaft Sites (13.0 acres)-- Primary archaeological impacts will occur from the construction of the tunnel shafts, with a small amount of secondary archaeological impacts from access road construction and work areas.

- Spoil Areas (66.0 acres)-- Secondary archaeological impacts will result from clearing, movement of heavy machinery, soil compaction, and access road construction. Most of this disturbance will not be harmful to cultural resources however, since many of the spoil areas will be located in gravel pits, where extensive ground disturbance has already taken place (Shaft B, 2.5 acres; Shaft C, about 20 of 35 acres; Shaft D, 2.5 acres; and Shaft E, 26 acres). It is likely that few undisturbed areas remain within the gravel pits, so that the possibility that cultural resources survive in these areas is very low.

- Tyngsborough Intake Structure and Treatment Plant (39.0 acres)-- Primary archaeological impacts will occur from construction of the water treatment plant (35.0 acres). Some secondary archaeological impacts

may result from road construction and work areas (4.0 acres). The impacts described above will affect unrecorded cultural resources that may exist at any of the proposed facility sites. No archaeological sites are recorded in any of the project areas, but a large prehistoric site (19-MD-1) is situated directly across the Merrimack River from the proposed Tyngsborough water treatment plant. Similar environmental characteristics suggest a high site potential in the proposed plant development area.

8.70.3 Significant Impacts

I. Measures of Significance Archaeological sites are considered significant if they are listed in, or eligible for inclusion in, the National Register of Historic Places. Such sites must have demonstrated importance in contributing to our understanding of local, regional, or national culture and history.

II. Significant Impacts Without adequate knowledge about the location and condition of significant prehistoric and historical cultural resources at the proposed facility sites for the Merrimack River Alternative, it is impossible to predict the effects of the alternative upon cultural resources. In general, however, it can be stated that, considering the size and scale of the construction required for the implementation of the Merrimack River Alternative, only a limited impact upon cultural resources is expected. This is true in part because a deep tunnel will be constructed, reducing the amount of surface disruption, and because most of the spoil sites will be located in areas already extensively disturbed by gravel pitting.

8.70.4 Mitigation/Enhancement Measures If the Merrimack River Alternative is selected as the preferred alternative, an intensive archaeological survey should be conducted to locate and identify currently unrecorded cultural resources that may exist at the location of the proposed facility sites. Special attention should be given to locating prehistoric sites in the area of the Tyngsborough water treatment facility, particularly due to its proximity to the Merrimack River. Undisturbed portions of the spoil areas should also be examined.

BIBLIOGRAPHY

MHC
1979 Cultural Resources in Massachusetts: A Model for Management. Massachusetts Historical Commission. Boston, Massachusetts.

MHC Files
Prehistoric Site Files of the Massachusetts Historical Commission. Boston, Massachusetts.

Appendices

TABLE OF CONTENTS

APPENDICIES

	Page	
Appendix 8-1	A-1	Engineering Drawings
Appendix 8-2	A-17	Cost Estimating Worksheets
Appendix 8-3	A-53	Results of MDC Model Runs
Appendix 8-4	A-57	Unit Cost Calculations
Appendix 8-5	A-65	Analysis of Tunnel vs. Pipeline
Appendix 8-6	A-71	Technical Appendix on Water Quality for Task 8: Merrimack River Alternative, (Published Under Separate Cover), Prepared By: Normandeau Associates, Inc.
Appendix 8-7	A-73	Technical Appendix on Aquatic Ecology for Task 8: Merrimack River Alternative, (Published Under Separate Cover), Prepared By: Normandeau Associates, Inc.
Appendix 8-8	A-75	Technical Appendix on Terrestrial Ecology for Task 8: Merrimack River Alternative, (Published Under Separate Cover), Prepared By: Normandeau Associates, Inc.

APPENDIX 8-1

ENGINEERING DRAWINGS

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PLAN
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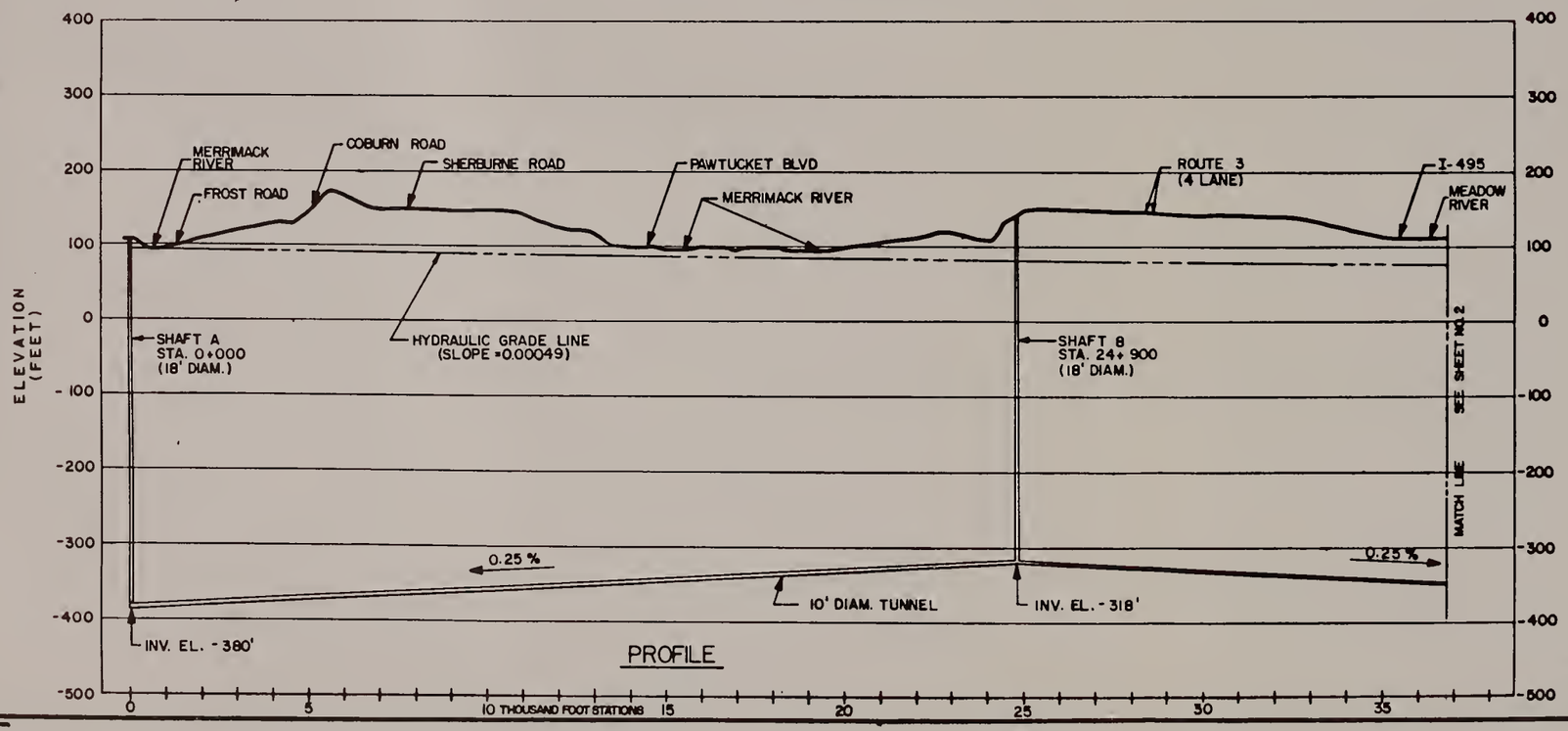

PROFILE

HORIZONTAL SCALE 1:25,000
VERTICAL SCALE 1"=100'

GENERAL NOTES

1. SOURCE OF MAPPING FOR PLANS WAS U.S.G.S. TOPOGRAPHIC MAPS FOR BILLERICA, BOSTON NORTH, LEXINGTON, LOWELL, NASHUA SOUTH, READING, WESTFORD & WILMINGTON QUADRANGLES.
2. FOR WATER TREATMENT PLANT LAYOUT, SEE DWG. SK-M-007.

NO.	DATE	REVISIONS	BY	CHKD	DESIGN SUPV.	ENGR.	PROJ. ENGR.	APPR.
1	5/7/85	ISSUED WITH FINAL REPORT	DB					
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MDC WATER SUPPLY STUDY & EIR

MERRIMACK RIVER ALTERNATIVE PLAN AND PROFILE SHEET NO. 1

JOB No.	DRAWING No.	REV.
15322	SK-M-001	1

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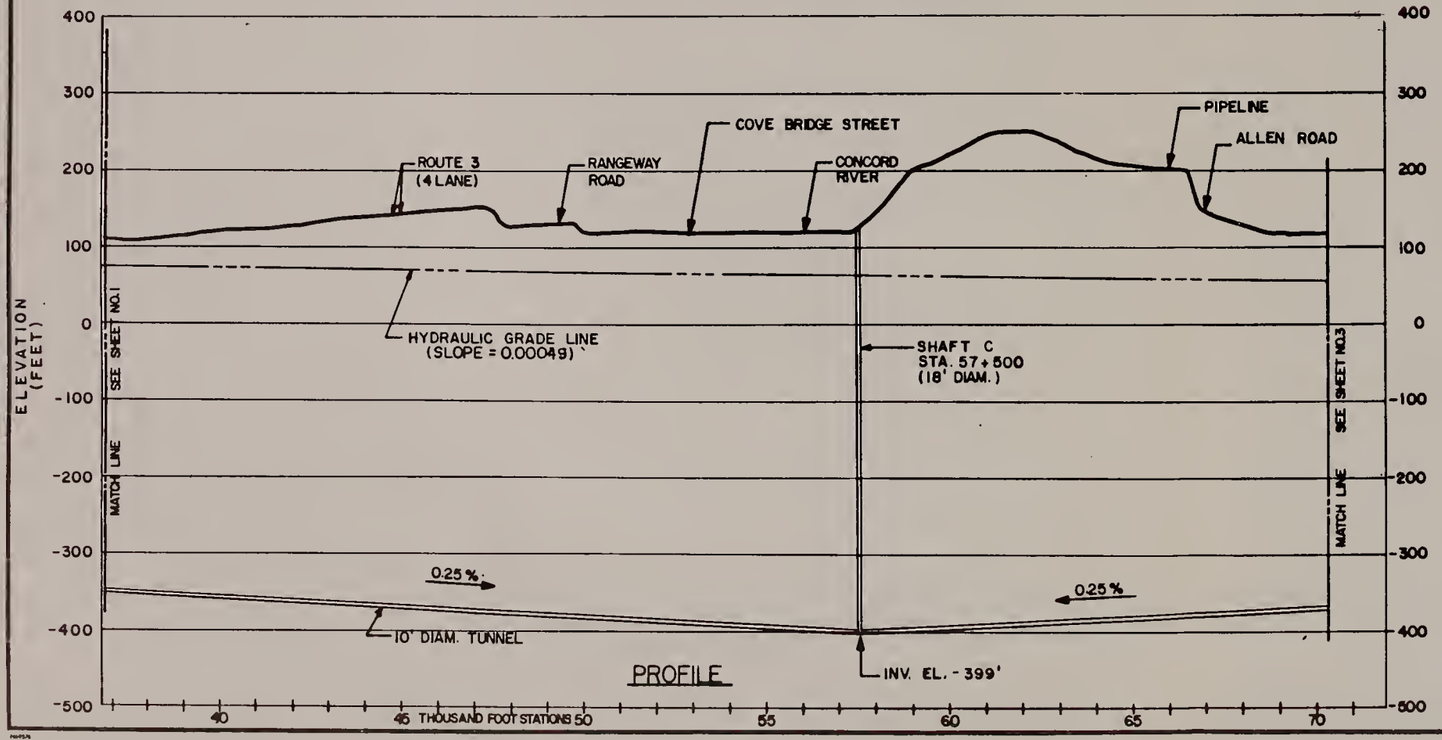

PROFILE

HORIZONTAL SCALE 1: 25,000
VERTICAL SCALE 1" = 100'

NOTES

1. SEE DWG. SK-M-001 FOR GENERAL NOTES

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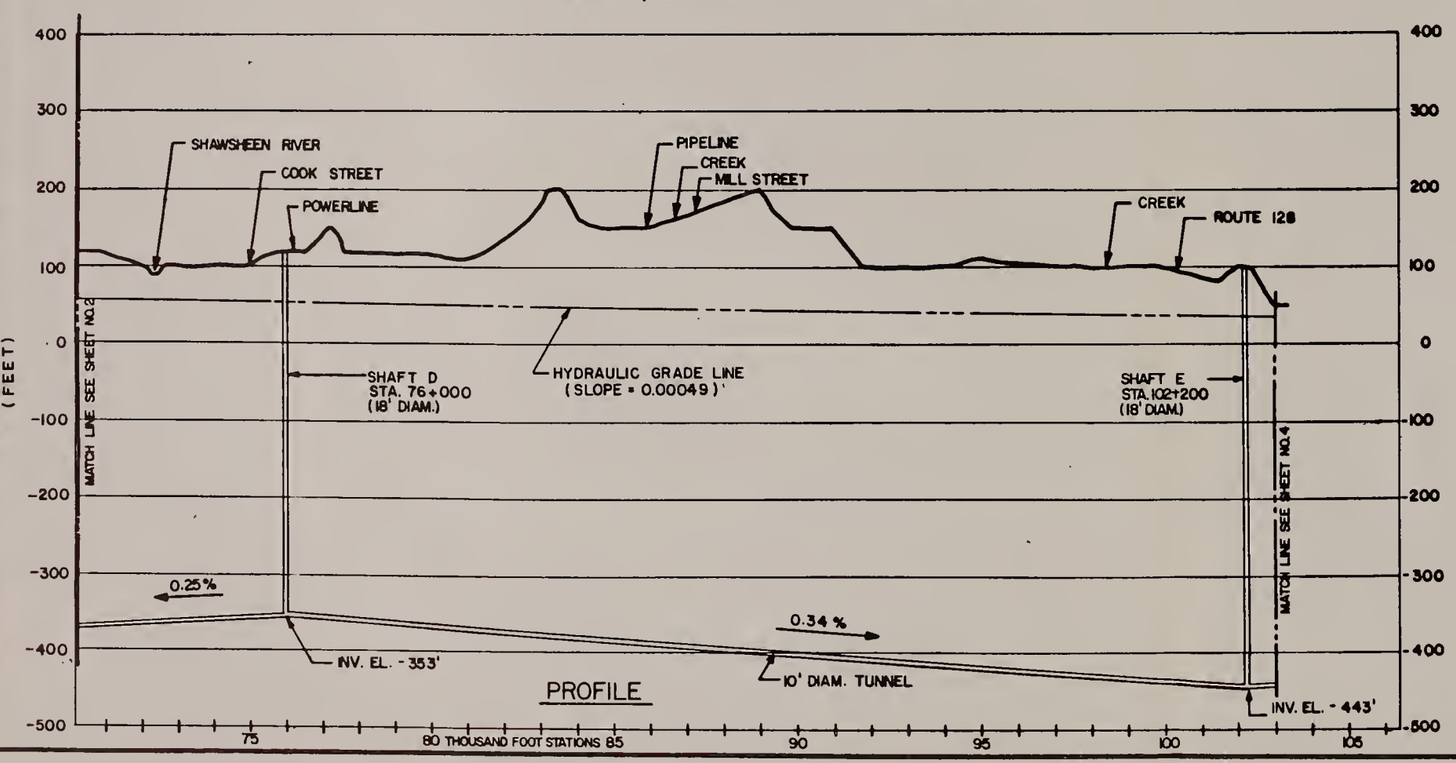

PROFILE

HORIZONTAL SCALE 1:25,000
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NOTES

1. SEE DWG. SK-M-001 FOR GENERAL NOTES.

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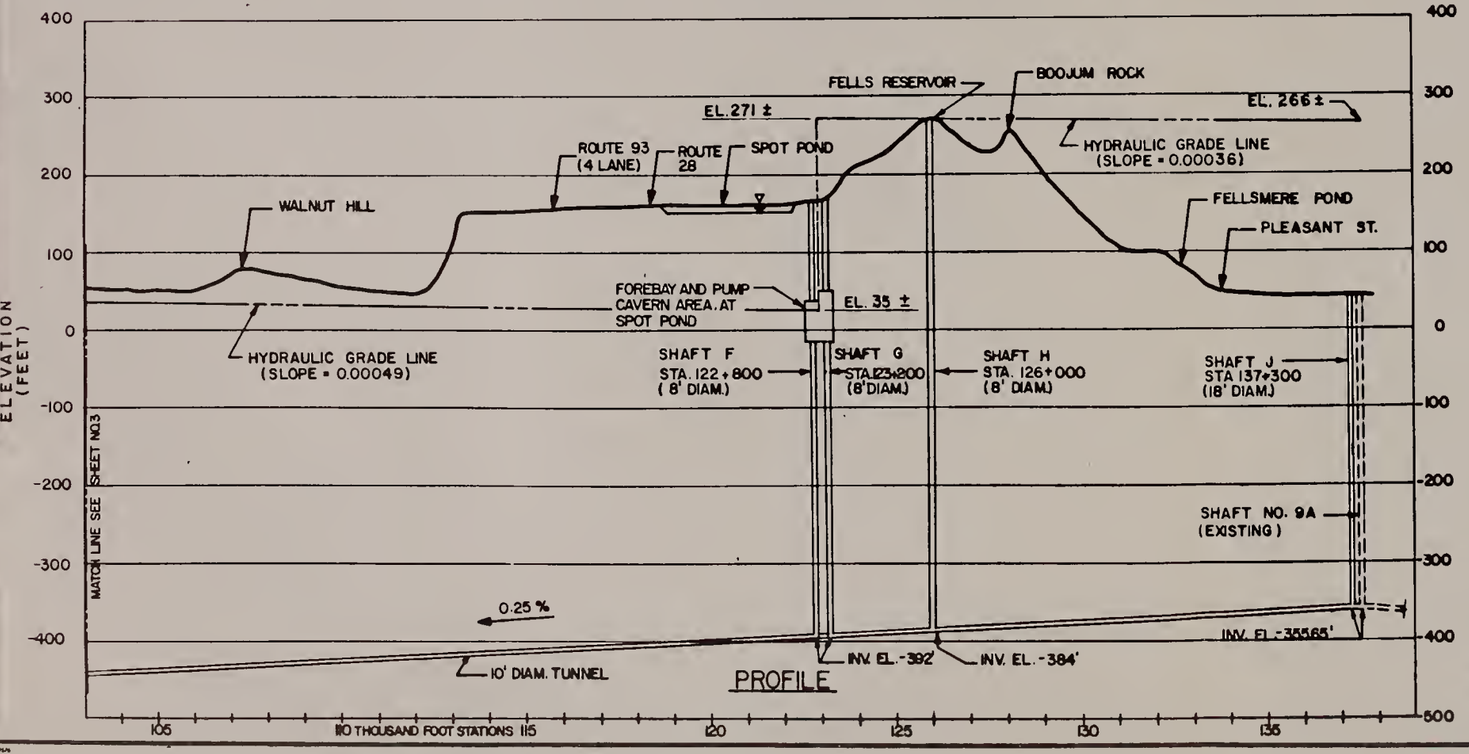

HORIZONTAL SCALE 1:25,000
VERTICAL SCALE 1"=100'

NOTES

1. SEE DWG. SK-M-001 FOR GENERAL NOTES.
2. FOR DETAILS OF PUMPING FACILITIES AT SPOT POND, SEE DWG. SK-M-005.

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MERRIMACK RIVER ALTERNATIVE PLAN AND PROFILE SHEET NO. 4

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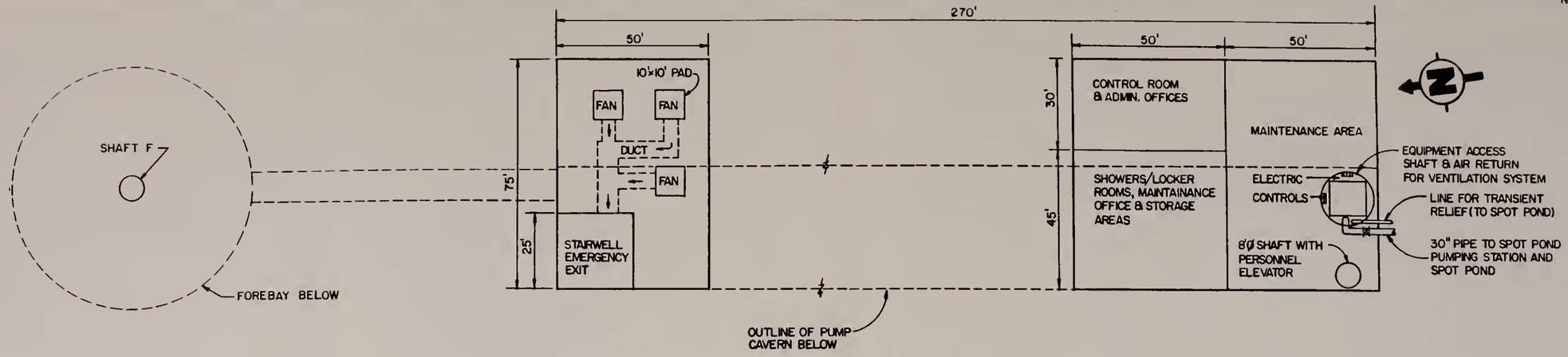
NOTE: THIS IS A CONCEPTUAL LAYOUT. ALL DIMENSIONS ARE APPROXIMATE



PLAN – ABOVE GROUND FACILITIES

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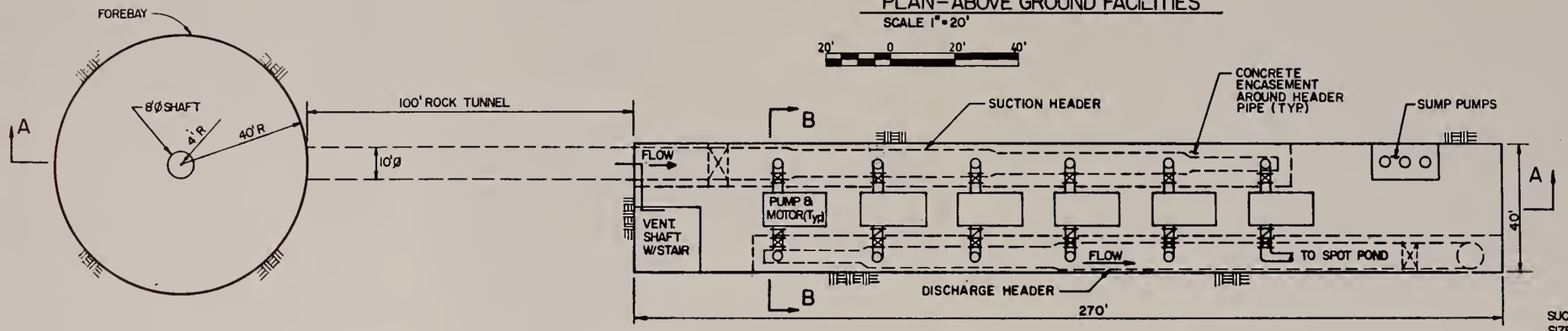

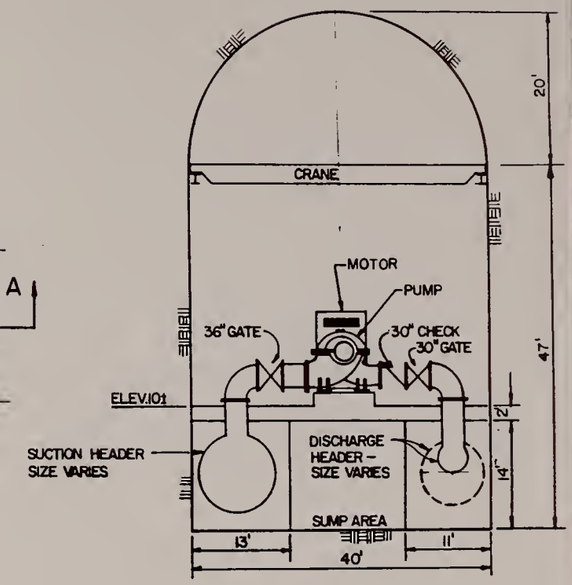

PLAN – UNDERGROUND PUMP CAVERN

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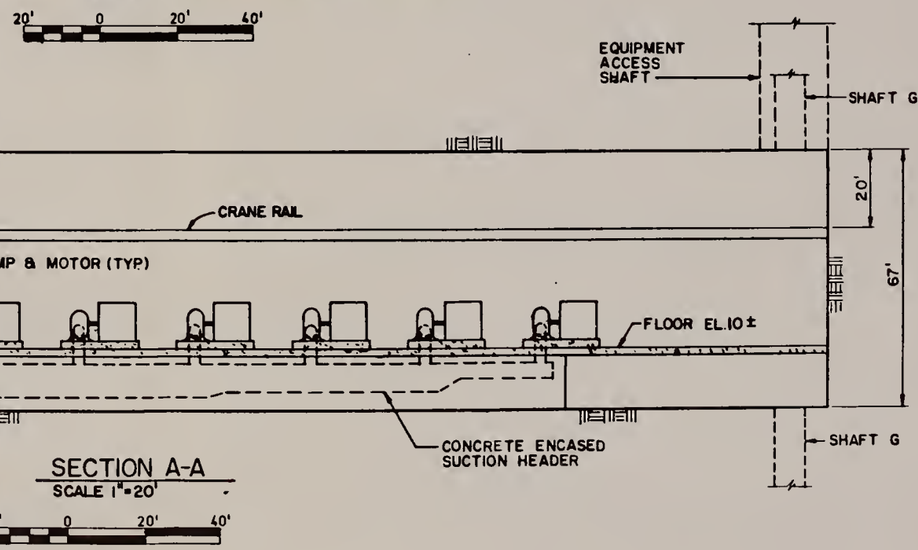

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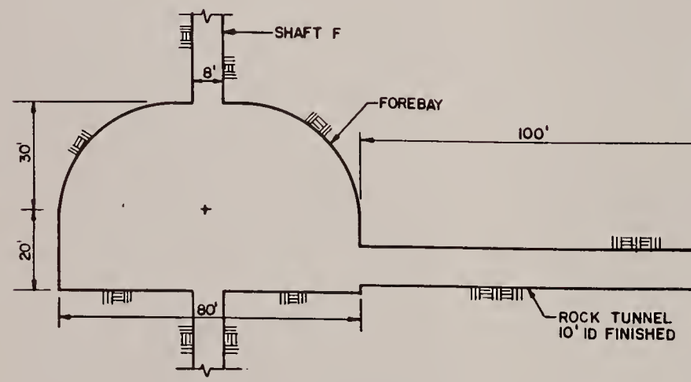

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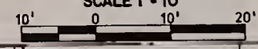

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MERRIMACK RIVER ALTERNATIVE
PROPOSED PUMPING FACILITIES AT SPOT POND

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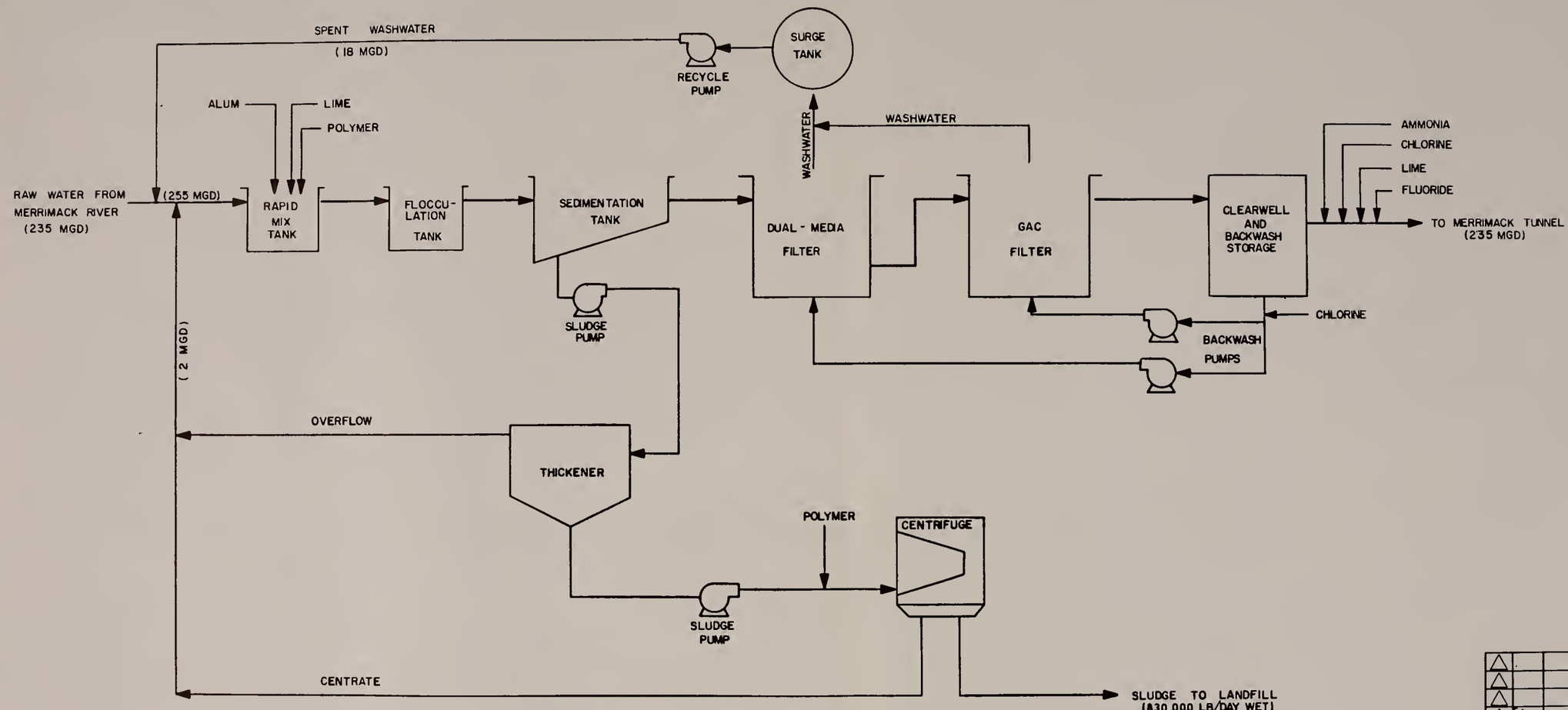

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MERRIMACK RIVER ALTERNATIVE WTP FLOW DIAGRAM

JOB No.	DRAWING No.	REV.
15322	SK-M-006	1

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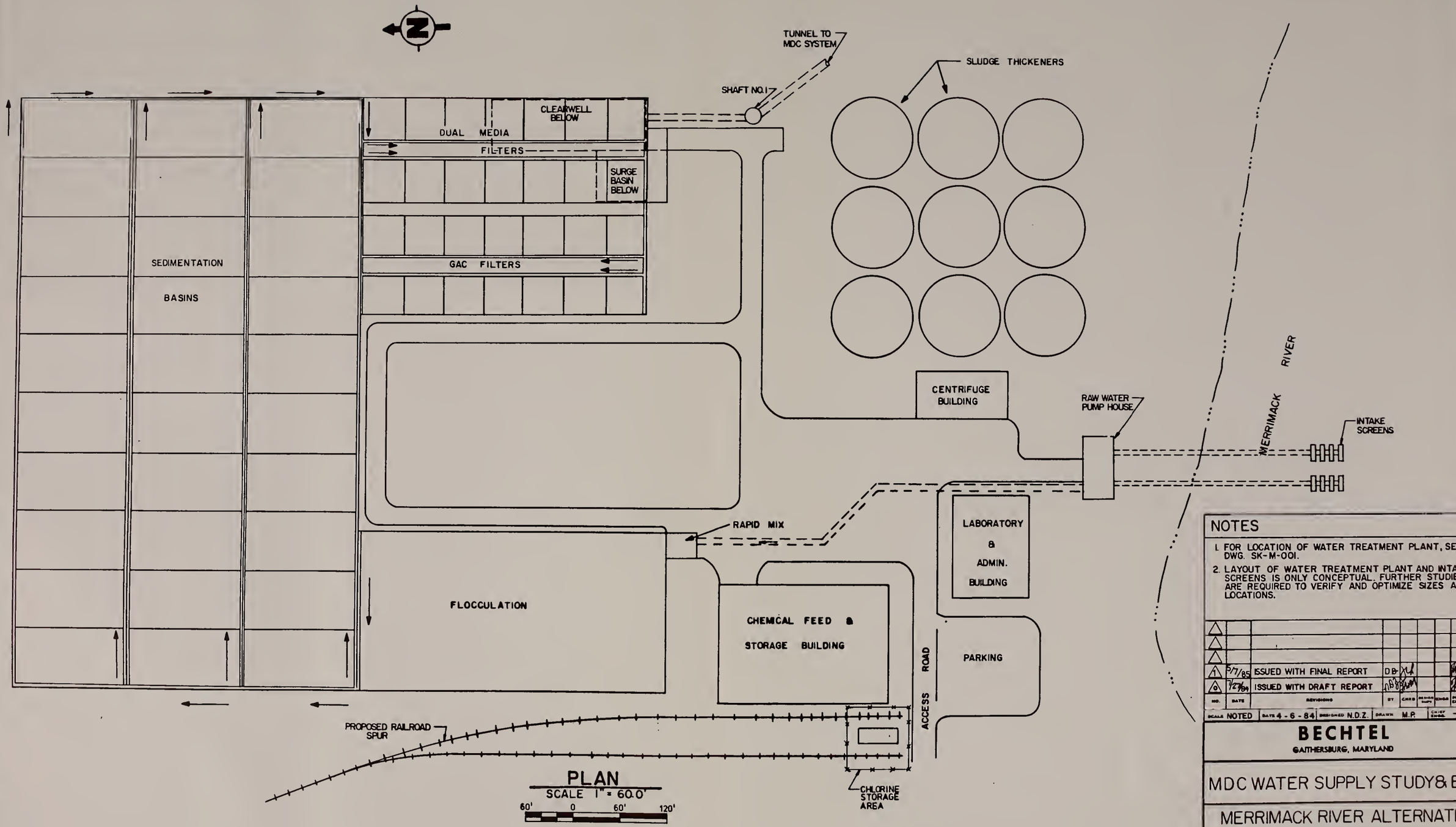

NOTES

1. FOR LOCATION OF WATER TREATMENT PLANT, SEE DWG. SK-M-001.
2. LAYOUT OF WATER TREATMENT PLANT AND INTAKE SCREENS IS ONLY CONCEPTUAL. FURTHER STUDIES ARE REQUIRED TO VERIFY AND OPTIMIZE SIZES AND LOCATIONS.

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MDC WATER SUPPLY STUDY & EIR

MERRIMACK RIVER ALTERNATIVE WTP LAYOUT

JOB No.	DRAWING No.	REV.
15322	SK-M-007	1

22 x 34 "D" SIZE

APPENDIX 8-2

COST ESTIMATING WORKSHEETS

WMH/HAJ/EJR
PREPARED BY

FWMaister
CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

15322-008
JOB NO.

6-11-81
DATE

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

SUMMARY - TUNNEL BORING MACHINE 10'-0" ID
PREPARED FOR

SHEET 1 OF 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK RIVER INTAKE	1	LS			4,500,000	
	WATER TREATMENT PLANT	1	LS			115,800,000	
	[illegible] LANDFILL						
	TUNNEL W/Reinf Conc. Lining (TBM)	136,900	LF	1272.85	174,250,000	174,250,000	
	SHAFTS						
	Shaft A 18'-0" ID	560	LF	4000	2000,000 ✓		
	B	470	LF	4000	1880,000 ✓		
	C	540	LF	4000	2160000 ✓		
	D	480	LF	4000	1920000 ✓		
	E	550	LF	4000	2200000 ✓		
	F 8'-0" ID	570	LF	2120	1,208,000		
	G 8'-0" ID	570	LF	2120	1208400 ✓		
	H	660	LF	2120	1399200 ✓		
	J 18'-0" ID	360	LF	4000	1,440,000		
	ROUND-OFF				440		
	TOTAL SHAFTS					15,420,000	
	SPOIL PILES + CONTR WORK AREAS	1	LS			1,690,000	
	PUMPING FACILITY & SPOT POND	1	LS			14,170,000	
	CONNECTION TO MDC SHAFT 9A	1	LS			150,000	
	DEWATERING	1	LS			500 000	
	PIPELINE & CONN. TO SPOT POND	1	LS			400,000	
	48" DISTRIBUTION PIPELINE	14,500	LF	[illegible]		8,100,000	

A-19

H&CF CSE 523 (3-80)

ESTIMATE SUMMARY

PREPARED BY

FW Mateliner
CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY - Merrimack River Division
PROJECT

Summary
PREPARED FOR

15322-008
JOB NO.

25 May 1984
DATE

SHEET 2 OF 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	SHAFT TO RESERVOIR CONNECTION @ FELLS RESERVOIR	1	LS			300 000	
	AERATION & CHEMICAL ADDITION @ SPOT POND	0	LS			0	DELETED
	TOTAL CONSTRUCTION COST (July 1982 pricing level)					335,270,000	
	CONTINGENCY					50,290,000	15% of Total Constr. Cost
	ENG. & CONST. MNGMT FEES					38,560,000	10% of TOTAL Cost ABOVE Incl. Pilot Plant Studies
	LAND & Right of Way COSTS					4,310,000	
	LEGAL, FISCAL & Adm. FEES					1,070,000	0.25% of TOTAL COST ABOVE
	INTEREST During CONSTRUCTION					64,430,000	15 % of TOTAL COST Above based on 3 yr. CONSTR. Period
	TOTAL CAPITAL COST.					493,930,000	

ESTIMATE SUMMARY

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

15322-008
JOB NO.

14 May 1984
DATE

SHEET 3 OF 30

M.D.C. WATER SUPPLY - Merrimack River Diversion
PROJECT

Merrimack River Intake
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	INTAKE STRUCTURE/CIVIL WORK						
	Excavation						
	Common	6750	CY	6.00	40500 ✓		
	Rock	6750	CY	16.00	108000 ✓		
	Backfill	7400	CY	10.00	74000 ✓		
	Concrete						
	Pump House	500	CY	350.00	175000 ✓		
	Baffle Wall	90	CY	350.00	31500 ✓		
	Pipe Encasement	1150	CY	200.00	230,000 ✓		
	Reinf. Steel	115	tons	900.00	103500 ✓		
	Sheeting	20000	SF	21.50	430000 ✓		
	Dewatering	1	LS		50000 ✓		
	INTAKE SCREENS	8	EA	60,000	480,000 ✓		
	(6'Φ x20' long Johnson T72-B-130)						
	PIPING: SCREENS TO						
	INTAKE STRUCTURE						
	72"Φ Header Pipe	600	LF	700	420,000 ✓		
	48"Φ Tee Pipe	50	LF	450	22500 ✓		
	2"Φ Air Backwash Pipe	2000	LF	60	120000 ✓		
	6'x6' Sluice Gate	2	EA	30000	60000 ✓		
	8"Φ Butterfly Valve	8	EA	3000	24000 ✓		
	EQUIPMENT: INTAKE +						
	WET WELL						
	Pumps 54,400 gpm + 40' TDH	4	EA	410,000	1,640,000		
	Water Level Alarm	1	LS		10000 ✓		
	Pump Control System	1	LS		20000 ✓		
	Overhead Crane 20T	1	EA		50,00		
	Maint. Shop	1	LS		40,000 ✓		
	Air Receivers 250ft³	4	EA	10,000	40000 ✓		
	@ 100psig						
	Compressor 100psig 105CFM	1	EA	3000	3000 ✓		

A-21

H&CF CSE 623 (3-80)

ESTIMATE SUMMARY

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

15322-008
JOB NO.

15 May 1984
DATE

SHEET 4 OF 30

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

Merrimack River Intake
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	PRE ENGINEERED BUILDING	3200	SF	40 ~~00~~	128,000		
	(40'x80')	(1	EA)				
	FLOW METERING + AUTOMATIC CONTROL	1	LS		20,000 ✓		
	WATER MONITORING STATION	1	LS		50,000		
	ELECTRICAL	1	LS		50,000		
						* 4,490,000	
				use		4,500,000	

A-22

H&CF CSE 523 (3-80)

ESTIMATE SUMMARY

NOZEIFLEK
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

MDC WATER SUPPLY STUDY
PROJECT

MERRIMACK RIVER ALTERNATIVE
PREPARED FOR

15322-005
JOB NO.

6/19/84
DATE

SHEET 5 OF 33

NO	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK WATER TREATMENT PLANT						
	PUMPS						
	SLUDGE PUMPING TO THICKENERS 1390 gpm, 30' TDH	1	L.S.		138,000		
	SLUDGE PUMPING TO CENTRIFUGE 277 gpm, 50' TDH	1	L.S.		60,000		
	RECYCLE PUMPS-VERT. TURBINE 15,200 gpm, 30' TDH	1	L.S.		100,000		
	PROCESS WATER PUMPS 17 gpm @ 50 psi	1	L.S.		28,000		
	POLYMER TRANSFER PUMP 100 gpm @ 50' TDH	1	L.S.		10,000		
	POLYMER FEED PUMPS 150 gpm @ 50' TDH	1	L.S.		2,000		
	ALUM FEED PUMPS	1	L.S.		22,000		
	SUB TOTAL				360,000		

A-23

HRCE CSE 523 (3-80)

ESTIMATE SUMMARY

H. D. ZEISER
PREPARED BY

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

15322-008
JOB NO

6/19/84
DATE

SHEET 6 OF 33

MDC WATER SUPPLY STUDY
PROJECT

MERRIMACK RIVER ALTERNATIVE
PREPARED FOR

NO	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK WATER TREATMENT PLANT						
	TANKS						
	ALUM STORAGE TANK 40'Ø X 20'H	2	EA		100,000		
	POLYMER STORAGE TANK 10'Ø X 12'H	1	EA		6,000		
	POLYMER AGING TANK 12'Ø X 22'H	4	EA.		46,000		
	MIXERS						
	RAPID MIX TANKS (~30 HP ea.)	8	EA.		120,000		
	FLOCCULATORS (3 HP ea.)	16	EA.		160,000		
	POLYMER STORAGE MIXER (~7.5 HP)	1	EA		9,000		
	POLYMER DILUTION MIXER	4	EA.		32,000		
	ALUM STORAGE MIXER (7.5 HP)	1	EA.		10,000		
	SUB TOTAL				783,000		

A-24

BECHTEL CSE 523 (3-80)

ESTIMATE SUMMARY

N. D. ZEIGLER
PREPARED BY

[illegible]
CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

15322-004
JOB NO.

6/19/84
DATE

SHEET 7 OF 30

MDC WATER SUPPLY STUDY
PROJECT

MERRIMACK RIVER ALTERNATIVE
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK WATER TREATMENT PLANT						
	[illegible] ESTIMATE						
	SEDIMENTATION TANK RAKES (150'x75'x5 ea)	30	EA		3,780,000		
	DUAL MEDIA FILTERS 4 CELLS/FILTER, 676 ft²/cell	14	EA.		5,140,000		
	GAC FILTERS [illegible] 676 ft²/cell	14	EA.		6,930,000		
	SLUDGE THICKENERS 100' x 12', 7854 ft²/ea	9	EA.		1,230,000		
	BASKET CENTRIFUGES CAPACITY = 500,000 #/hr	2	EA.		476,000		
	LIME FEED SYSTEM 31,900 lb/day	1	L.S.		577,000		
	AMMONIA FEED SYSTEM 1.0 ppm, 3300 lb/day	1	L.S.		28,000		
	CHLORINE FEED SYSTEM 10,600 lb/day	1	L.S.		60,000		
	EVAPORATOR, ON-SITE STORAGE TANKS & ASSOCIATED EQUIPMENT	1	L.S.		50,000		
	SUB TOTAL				18,271,000		

A-25

H&C CSF 523 (3-80)

ESTIMATE SUMMARY

PREPARED BY: F. W. MATTHEWS

CHECKED BY:

TYPE OF ESTIMATE: ORDER OF MAGNITUDE

PROJECT: MDC WATER SUPPLY STUDY

PREPARED FOR: MERRIMACK RIVER ALTERNATIVE

JOB NO. 15322-008

DATE 6/19/84

SHEET 4 OF 50

NO	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK WATER TREATMENT PLANT						
	BUILDINGS						
	CENTRIFUGE BLDG. 120' X 60'	7200	SF	43			
	ADMIN / LAB / MAINT. BLDG. 100' X 130'	13,000	SF	43			
	CHEMICAL STORAGE BLDG.	33,000	SF.	43			
	FILTER BUILDING	103,600	SF	15			
	TOTAL	53,200	SF		3,854,000		
	CONCRETE						
	RAPID MIX TANKS 25'X8'X12' - 6 @ 20 CU YD	270	CY	360	100,000		
	FLOCCULATION TANKS 100'X50'X12' 16 @ 350 CU YD	5600	CY	360	2,020,000		
	SEDIMENTATION TANKS 120'X75'X15' 8 @ 133 CU YD	21,000	CY	360	7,920,000		
	DUAL MEDIA FILTERS 14 @ 1430 CU YD	20,000	CY	360	7,200,000		
	GAC FILTERS 14 @ 1430 CU YD	20,000	CY	360	7,200,000		
	RAIL SIDING				250,000		
	SUB TOTAL				28,544,000		

HRCE CSE 523 (3-80)

D. ZEISER
PREPARED BY

F.N. MATTHEW
CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

ESTIMATE SUMMARY

MDC WATER SUPPLY STUDY
PROJECT

MERRIMACK RIVER ALTERNATIVE
PREPARED FOR

15322-009
JOB NO.

6/19/84
DATE

SHEET 9 OF 30

NO	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	MERRIMACK WATER TREATMENT PLANT						
	SLUDGE THICKENERS 9 - 474 CY EA.	4266	CY	360	1,540,000		
	SLUDGE HANDLING	1	LS		536,000		
	CLEARWELL - 1 MG 100' X 135' X 12'	780	CY	360	280,000		
	SURGE FACILITY - 450,000 GAL 90' X 67' X 12'	327	CY	360	120,000		
	LANDFILL	1	LS		24,000,000		
	OFF SITE CARBON REGENERATION	1	LOT		2,400,000		
	INTAKE PIPING - 9'Ø, [illegible]	530	FT	700	370,000		
	EFFLUENT PIPING - 9'Ø, 16 FT. [illegible]	125	FT	800	100,000		
	SUB TOTAL P.				360,000		
	SUB TOTAL E				793,000		
	SUB TOTAL I				18,271,000		
	SUB TOTAL T				28,544,000		
	MECH. & ELEC. EQUIP. ITEMS				[illegible]		
	TOTAL DIRECT COST				93,304,000		
	DISTRIBUTION				12,000,000		
	CONTIN.				10,500,000		
	TOTAL CAPITAL [illegible]				115,800,000		

A-27

HBCI CSE 523 (3-80)

WM-11 / E&R
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

16'Φ ID TUNNELS - TBM ALT
PREPARED FOR

15322-008
JOB NO.

6/12/84 E&R
15 May 1984
DATE

SHEET 10 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	DRILL + BLAST TUNNEL						
	Excavation	136900	LF	850	116,365,000		
	Rock Bolts 3/8" x 8' long	542,400	LF	10	5,424,000		
	Steel Sets + Lagging	5300	EA	600	3,180,000		
	Reinf. Concrete Lining	136900	LF	360	49,284,000		
						174,253,000	
					SAY	174,250,000	

HACE-CSE 523 (1/80)

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

MRC WATER SUPPLY - Merrimack River Diversion
PROJECT

SHAFTS
PREPARED FOR

15322-008
JOB NO.

16 May 1984
DATE

SHEET 11 of 20

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Shaft A 18'-0" ID						
	Excavation + Support	500	LF	3000	1500,000		
	Reinf. Conc. Lining	500	LF	1000	500,000		
	total					2,000,000	
	Shaft B 18'-0" ID						
	Excavation + Support	470	LF	3000	1410,000		
	Reinf. Conc. Lining	470	LF	1000	470000		
	total					1880000	
	Shaft C 18'-0" ID						
	Excavation + Support	540	LF	3000	1620000		
	Reinf. Conc. Lining	540	LF	1000	540,000		
	total					2,160,000	
	Shaft D 18'-0" ID						
	Excavation + Support	480	LF	3000	1440000		
	Reinf. Conc. Lining	480	LF	1000	480000		
	total					1920000	
	Shaft E 18'-0" ID						
	Excavation + Support	550	LF	3000	1650000		
	Reinf. Conc. Lining	550	LF	1000	550,000		
	total					2,200,000	
	Shaft F 8'-0" ID						
	Excavation + Support	570	LF	1600	912,000		
	Reinf. Conc. Lining	570	LF	520	296,400		
	total					1,208,400	

A-29

H&CF CSE 523 (3-80)

WM H
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

SHAFTS
PREPARED FOR

15322-008
JOB NO.

16 May 1984
DATE

SHEET 12

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Shaft G 8'-0" ID						
	Excavation + Support	570	LF	1600	912000 ~		
	Reinf. Conc. Lining	570	LF	520	296400		
	total					1208400	
	Shaft H 8'-0" ID						
	Excavation + Support	660	LF	1600	1056000 ~		
	Reinf. Conc. Lining	660	LF	520	343200		
	total					1399200	
	Shaft J 18'-0" ID						
	Excavation + Support	360	LF	3000	1,080,000		
	Reinf. Conc. Lining	360	LF	1000	360,000		
	total					1,440,000	

A-30

HACE CSE 523 (3-80)

WMH
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

15322-008
JOB NO.

16 May 1984
DATE

SHEET 13 of 30

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

Spoil Piles + Contraction Work Areas
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Clearing + Grubbing	140	Acre	750	105000		
	Placing + Compacting Spoil	920,000	CY	1 00	920,000		
	Hauling Spoil	155,000	CY	4 00	620,000		
	Revegetation - Work Areas	30 (Assumed)	Acre	1000	30000		
						1,675,000	
					SAY	1,680,000	

ESTIMATE SUMMARY

PREPARED BY HBJ

CHECKED BY

TYPE OF ESTIMATE ORDER OF MAGNITUDE

PROJECT MDC WATER SUPPLY - MERRIMAK RIVER DIVERSION

PREPARED FOR

15322-008 JOB NO.

MAY 1984 DATE

SHEET 14 & 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	PUMPING FACILITY AT SPOT POND						
	SUMMARY						
	FOREBAY	1	LS		785 000		
	TUNNEL	1	LS		227 000		
	U.G. PUMP CAVERN	1	LS		3517 000		
	U.G. PUMP CAVERN SHAFTS	1	LS		1086 000		
	ABOVE GROUND FACILITIES	1	LS		975,000		
	MECHANICAL	1	LS		3 758 000		
	ELECTRICAL	1	LS		2 832 000		
	CONTROLS, COMMUNICATION, CLOSED CIRCUIT TV, AND FIRE PROTECTION	1	LS		390,000		
	TOTAL					14,170,000	

A-32

USCF CSE 523 (3-80)

PREPARED BY HAJ

CHECKED BY

ORDER OF MAGNITUDE
TYPE OF ESTIMATE

ESTIMATE SUMMARY

MDC WATER SUPPLY - MERRIMAK RIVER DIVERSION
PROJECT

PREPARED FOR

15 322-008
JOB NO.

21 MAY 1984
DATE

SHEET 15 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	THE SPOT POND FACILITY -						
	FOREBAY						
	UNDERGROUND DOME, h = 50', ϕ = 80'						
	EXCAVATE ROCK	7550	CY	80.00	604 000		UNIT PRICE INCLUDES COST
	ROCK BOLTS ϕ 1¼" lg 20'	3500	LF	30.00	105 000		FOR O-B-
	STEEL SETS & LAGGING	0	TON	2400.00	0		
	WIRE MESH	17 600	SF	1.75	30 800		
	SHOTCRETE t = 3"	160	CY	280.00	44 800		
	REINFORCING STEEL	0	TON	1100.00	0		
	CONCRETE	0	CY	220.00	0		W/O O-B-
	ROUND-OFF				400		
	TOTAL				785 000		
	TUNNEL						
	L = 100 FT, ϕ 10' ID						
	EXCAVATION IN ROCK	511	CY	300.00	153 300		
	ROCKBOLTS, Allow 3/4", lg 10'	500	LF	10.00	5 000		
	WIREMESH, Allow	1000	SF	1.75	1750		
	STEEL SETS & LAGGING	5	TON	2400.00	12 000		
	REINFORCING STEEL Allow	6	TON	1100.00	6600		
	CONCRETE LINING	220	CY	220.00	48 400		
	ROUND-OFF				<50>		
	TOTAL				227 000		

A-33

NAVFAC CSE 623 (3-80)

ESTIMATE SUMMARY

PREPARED BY HAJ

CHECKED BY

TYPE OF ESTIMATE ORDER OF MAGNITUDE

PROJECT MDC WATER SUPPLY - MERRIMACK RIVER DIVERSION

JOB NO. 15322-008

DATE 21 MAY 1984

SHEET 16 of 30

PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	THE SPOT POND FACILITY (CONT.)						
	UNDERGROUND PUMP CAVERN						
	L = 270', W = 40', h = 67'						
	EXCAVATION IN ROCK	25 100	CY	100.00	2 510 000		
	ROCK BOLTS Ø 1¼", lg 20'	9 500	LF	30.00	285 000		
	STEEL SETS & LAGGING						
	WIREMESH	47 400	SF	1.75	X295.0		
	SHOTCRETE t = 3"	440	CY	280.00	123 300		
	CONCRETE (TECH, WALLS, INVERT)	0	CY	–	0		
	CONCRETE ENCASEMENT FOR HEADER PIPES	2360	CY	200.00	472 000		
	REINFORCING STEEL FOR ENCASEMENT	40	TON	1100.00	44000		
	ROUND-OFF				<250>		
	TOTAL				3 517 000		

WMH/HAJ
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

15322-009
JOB NO.

17 May 1984
DATE

SHEET 17 & 30

MDC WATER SUPPLY – Merrimack River Diversion
PROJECT

Pumping Facility & Spot Pond - Underground Pump Cavern Shafts
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Emergency Exit Shaft 18'ϕ ID	125	LF	4000	500,000		
	Grating Type Stair	160	LF	250.00	40 000		SPIRAL, IN VENTILATION SHAFT
	Equipment Shaft. 18'ϕ ID	125	LF	4000	500,000		FOR VENTILATION AIR RETURN
	Protective Partition Wall	125	LF	370.00	46 300		(4x12) SF/LF - WIRE MESH
	PAID-OFF.				<3,000>		
	TOTAL U.G. PUMP CAVERN SHAFTS				1086 000		

HACE CSE 623 (3-80)

W Mift / HAJ
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

15322-008
JOB NO.

17 May 1984
DATE

SHEET 17 of 30

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

Pumping Facility & Spot Pond - Above Ground Facilities
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	Building 50' x 75'	3750	SF	40.00	150,000 -		
	Building 100' x 75'	7500	SF	40.00	300,000 -		
	Ventilation Equipment	1	LS	125 000	125 000		84 200 CFM
	Chlorination + Flouridation Equipment & Chemical Storage				ø		DELETED
	Electrical Switchyard - SUBSTATION	1	LS		0		INCLUDED W/ ELECTRICAL
	Overhead Crane 25 Ton	1	EA	100 000	100 000		
	PERSONNEL ELEVATOR 6'x6', 3500 lb	1	EA	100 000	100 000		IN THE 3 ϕ PRESSURE SHEET
	ROUND-OFF				0		
	MODIFICATION TO EXISTING SPOT POND FACILITY	1	LS		200,000		
	TOTAL				975,000		

H&CF CSE 523 (3-80)

A-36

HAJ/AW
PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

ESTIMATE SUMMARY

15322-008
JOB NO.

18 May 1984
DATE

SHEET 17 of 30

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

Pumping Facility @ Spot Pond - Mechanical
PREPARED FOR

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	PIPING, FITTINGS & VALVES						
	10'Φ ID }	50	LF	2080.00	104 000		
	9'Φ ID }	60	LF	1870.00	112 200		
	8'Φ ID } Headers	130	LF	1480.00	192 400		
	7'Φ ID }	130	LF	1130.00	146 900		
	4'Φ ID }	50	LF	460.00	23 000		
	36"Φ Suction Pipe	50	LF	160.00	8 000		
	30"Φ Discharge Pipe	30	LF	135.00	4 050		
	30"Φ Pressure Pipe	250	LF	135.00	33 750		
	12"Φ Transient Pressure Pipe	200	LF	55.00	11 000		
	8"Φ Discharge Pipe	200	LF	40.00	8 000		
	36"Φ Gate Valve	5	EA	46 000	230 000		
	30"Φ Gate Valve	8	EA	32 000	256 000		
	24"Φ Gate Valve	1	EA	17 000	17 000		
	120"Φ Gate Valve	1	EA	500 000	500 000		
	96"Φ Gate Valve	1	EA	300 000	300 000		
	12"Φ Gate Valve	4	EA	4000	16 000		
	30"Φ Check Valve	6	EA	26 000	156 000		
	12"Φ Check valve	3	EA	3500	10 500		
	36"Φ Close Radius Elbows	6	EA	1000.00	6 000		
	30"Φ Close Radius Elbows	9	EA	700.00	6 300		
	Pressure Relief Valve	1	EA	10 000.00	10 000		
	Vacuum Relief Valve	1	EA	10 000.00	10 000		
	Air Release Valve	1	EA	10 000.00	10 000		

H&CF CSE 623 (3-80)

ESTIMATE SUMMARY

PREPARED BY

CHECKED BY

Order of Magnitude
TYPE OF ESTIMATE

MDC WATER SUPPLY - Merrimack River Diversion
PROJECT

Pumping Facility @ Spot Pond - Mechanical
PREPARED FOR

15322-008
JOB NO.

18 May 1984
DATE

SHEET 20 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	PUMPS - Underground Cavern						
	IR 30x425 [illegible]	5	EA	260 000	1 300 000		
	IR 24x325 [illegible]	1	EA	132 000	132 000		
	Gould VJC Sump Pump	2	EA	18 000	36 000		
	General Service Sump Pump	1	EA	10 000	10 000		
	OVERHEAD CRANE 25T	1	EA	100,000	100, 000		
	Pump Platforms	1	LS	9 000	9 000		
	Pump - etc				<100>		
	Total				3,758, 000		

ESTIMATE WORKSHEET

15321-00B — JOB NO.
O/M — TYPE OF ESTIMATE
PROJECT M.I.C. HAZLE SUPPLY.
CLIENT
JOB LOCATION
TAKEOFF
PRICED JJ
CHECKED
APPROVED
DATE 5.23.84
SHEET 21 of 30

16/22

ITEM AND DESCRIPTION	QUANTITY	UNIT	UNIT COST	B/SC MHRS. UNIT	B/SC MHRS. TOTAL	$/MH	PLANT EQUIPMENT	BULK MATERIAL	LABOR	SUB CONT.	TOTAL
Summary											
Electrical.											
TRANSMISSION LINE/EQUIP SHT 2							562000	31600	632100	379300	1605000
Acc. Elect Equip/Bulks SHT 2							60000	1400	28400	100400	190200
Raceways/Cable SHT 3							76800	5200	96800	581100	236900
DIESEL GEN. SHT 4										800000	800000
										H 1982 Bid	
CODE							698800	38200	757300	1337800	2832100

H&CF CSE-626 (12 81)

BECHTEL

ESTIMATE WORKSHEET

15522-008 JOB NO.

O/M. TYPE OF ESTIMATE

PROJECT M.D.C. WATER SUPPLY STUDY.

CLIENT

JOB LOCATION

TAKEOFF

PRICED JJ

CHECKED

APPROVED

DATE 6-23-84

SHEET 22 of 53

ITEM AND DESCRIPTION	QUANTITY	UNIT	UNIT COST	B/SC MHRS. UNIT	B/SC MHRS. TOTAL	B/SC MHRS. $/MH	PLANT EQUIPMENT	BULK MATERIAL 6% LABOR	LABOR	OVHD/PROFIT SUB-CONT. 60% OF LABOR	TOTAL $/C LEVEL COST 1Q 1982
TRANSMISSION LINE.											
2-13.8 KV. SINGLE CKT WOOD POLE LINE, HEAVY LOADING OVER LEVEL TERRAIN. WITH GOOD ACCESS	20	MI	13.5K	1000	20,000	30.00	270000	30000	600000	360000	1260000
Price Base 1Q 1982											
20 MVA. MAIN TRANSFORMER 13.8/4.16 KV. 3PH, 60HZ OUTDOOR.	1	EA	132K	500	500	30.00	132000	7500	150000	90000	156750
13.8 KV Duplex Disc. SW.	1	EA	25K	170	170	30.00	25000	1800	36000	21600	30940
13.8 KV POTHEADS & CABLE.	1	LS			100	30.00	4000	1500	30000	18000	59500
4.16 KV. SWGR. -											
Incoming FDR 3000 A	1	EA	44K	30	30	30.	44000	1200	24000	14400	47600
MCC. 4.16 KV 2000 A.	1	EA	31K	70	70		31000	1100	21000	12600	34470
12.0 A	2	EA	18K	60	120		36000	1800	36000	21600	41940
TRANSITION/MTING CUBICLE.	2	EA	10K	40	80		20000	1200	21000	14400	23960
CODE								(10)		40	30
					21070	30.	562000	31600	632100	379300	16050000

BECHTEL

ESTIMATE WORKSHEET

15322-008
JOB NO.

O/M
TYPE OF ESTIMATE

PROJECT M.D.C. Water Supply
CLIENT
JOB LOCATION

TAKEOFF _____ APPROVED _____
PRICED JJ DATE 5.23.84
CHECKED _____ SHEET 23 of 30

ITEM AND DESCRIPTION	QUANTITY	UNIT	UNIT COST	B/SC MHRS. UNIT	B/SC MHRS. TOTAL	$/MH	PLANT EQUIPMENT	BULK MATERIAL	LABOR	SUB CONT.	TOTAL
SPOKANE STATION SERVICE	1	EA	12K	60	60	30	12000	90	1800	1080	14970
TRANSFORMER, DRY INDOOR 3PH. 60HZ.											
480V. SWGR -											
INCOMING FDR BKR	1	EA	5.2K	25	25	30	5200	40	750	450	6440
MCC FDR STARTER #4	1	EA	2.6K	15	15		2600	20	450	270	3340
" " #3	2	EA	.8K	6	12		1600	20	360	220	2200
" " #2	2	EA	.5K	4	8		1000	10	240	140	1390
" " #1	4	EA	.4K	3	12		1600	20	360	220	2200
LTG BRKR 100A	3	EA	.9K	2	6		1200	10	180	110	1500
MISC LIGHTING PANELS	2	EA	.9K	30	60	30	1800	90	1800	1000	4770
LIGHTING - FIXTURES											
CONDUIT AND CABLE											
PUMP CAVERN - 920W @ 1/2 MILE	920W	LF	4.15		-				3810	2100	5910
CONTROL ROOM - 750W @ 1/2	750W	LF	3.30		-				2480	1375	3855
FAN ROOM/SHAFT - 3750 @ 1/2 MILE	3750	LF	3.10		-				11250	6250	17500
MISC. STA. SHELL - 2300 @ 1/2 MILE	2300	LF	4.00		-				9200		9200
BUS - 4.16 KV SINGLE - 750 KCM	1500	LF	22	.5	750	30	35000	1100	22500	13500	72100
+ SUPPORTS, CABLE IN ELEC SHELL - 3/C 500 MCM AWG									(140)	(20)	(160)
CODE					918	30	60000	1400	28400	16400	190200

BECHTEL

ESTIMATE WORKSHEET

15322-008
JOB NO.

O/M
TYPE OF ESTIMATE

PROJECT MDC water Supply
CLIENT
JOB LOCATION

TAKEOFF
PRICED JJ
CHECKED

APPROVED
DATE 5-23-84
SHEET 24 of 50

ITEM AND DESCRIPTION	QUANTITY	UNIT	UNIT COST	DISC MHRS. UNIT	DISC MHRS. TOTAL	$/MH	PLANT EQUIPMENT	BULK MATERIAL	LABOR	SUB CONT	TOTAL
Raceways											
Tray 24" Power/control	460	LF	12.00	1.00	460	30.00	5520	690	13800	8280	28290
Conduit 5" Power Sub	900	LF	14.00	.70	660	30.00	12600	900	18000	10800	42300
" 2" Power Sub	900	LF	3.00	.30	270		2700	400	8100	4860	16060
" 1" Conf	900	LF	1.40	.02	18.0		490	270	5100	3240	11900
Flex 5"	6	EA	70	2	12		420	180	360	220	1180
" 1"	10	EA	10	1	10		100	150	300	180	730
Misc.							2330			2758	4.4..
Cable - 3/c 5 kV Power 4160V	400	LF	18.00	.1	360		1620	510	10800	6480	34020
3/c #10 4160V	200	LF	5.00	.18	36		1000	60	1080	650	2790
3/c 500MCM 4160V	400	LF	9.00	.30	120		3600	180	3600	2160	9540
3/c #10	2000	LF	.50	.05	100		1000	150	3000	1800	5950
12/c #14	3000	LF	1.70	.1	350		3950	5360	10500	6300	23280
Communication 5kV	30	LF	15	6	180		450	270	5400	3240	9360
" 600V	500	LF	.5	.3	150		250	280	4500	2700	7680
							2.4.5.0			23.5.0	2.6.1.0
Grounding Allow	1	LS			100	30	6000	150	3000	1800	10950
Misc. Support Hardware Allow	1	LS			100	30	5000	150	3000	1800	9950
Subsea Splices Allow Conduit and cable.	1	LS			200	30	15000	300	6000	3600	24900
CODE Adj							20	50	<4-0>	<10>	20
					3115		76800	5200	96800	58100	236900

A-42

H&CF CSE 626 (12 81)

BECHTEL

ESTIMATE WORKSHEET

15322-008
JOB NO.

O/M
TYPE OF ESTIMATE

PROJECT MOC Water Supply
CLIENT
JOB LOCATION

TAKEOFF
PRICED JJ
CHECKED

APPROVED
DATE 5-23-84
SHEET 25 of 30

20pg

ITEM AND DESCRIPTION	QUANTITY	UNIT	UNIT COST	M/HC MHRS. UNIT	M/HC MHRS. TOTAL	$/MH	PLANT EQUIPMENT	BULK MATERIAL	LABOR	SUB-CONT.	TOTAL
SPET POND - DIESEL GEN:	1	EA									
2000 KW, 4160V, 1800 RPM											
60 HZ, 3PH AND Associated											
Equipment:											
	2000	KW	400							800000	800000
CODE										800000	800000

H&CF CSE 626 (12 81)

ESTIMATE SUMMARY

PREPARED BY HAJ

CHECKED BY

TYPE OF ESTIMATE ORDER OF MAGNITUDE

PROJECT MDC WATER SUPPLY - MERRIMAK RIVER DIVERSION

PREPARED FOR

JOB NO. 15322-002

DATE MAY 1984

SHEET 25 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	CONTROLS						
	VALVES, Allow	1	LS	50 000	50 000		
	Pumps - Allow	1	LS	50 000	50 000		
	VENTILATION	1	LS	0	0		INCLUDED W/ MECHANICAL
	COMMUNICATION, Allow	1	LS		60 000		
	CLOSED CIRCUIT TV, Allow	1	LS		70 000		
	FIRE PROTECTION SYSTEM	1	LS		60 000		
	SYSTEM AUTOMATION & COMMUNICATIONS W/ MDC SYSTEM	1	LS		300,000		
	MODEL STUDIES	1	LS		200 000		
	TOTAL				990,000		

A-44

USCE CSE 523 (3-80)

ESTIMATE SUMMARY

PREPARED BY HAJ

CHECKED BY

TYPE OF ESTIMATE Order of Magnitude

PROJECT MDC Water Supply – Merrimack River Diversion

PREPARED FOR

15322-008
JOB NO.

25 May 1984
DATE

SHEET 27 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	CONNECTION TO MDC SHAFT 9A						
	SHUT-OFF SURFACE DISTRIBUTION PIPES FROM MDC SHAFT 1A	1	LS		2 000		BY EXISTING GATES & VALVES
	SHUT-OFF FLOW FROM MDC SHAFT 9 TO 9A AT MDC SHAFT 9	1	LS		2 000		BY EXISTING GATES & VALVES
	DEWATER TUNNEL	330 000	GAL	.03	9 900		
	REMOVE CONCRETE PLUG	± 200	CY	250.00	50 000		
	CONNECT TUNNELS AND REPAIR LINING AS REQUIRED, ALLOW	1	LS		10 000		
	INSTALL GATE IN MDC SHAFT 9A TO SHUT-OFF FLOW FROM MERRIMAK SYSTEM, ALLOW	1	LS		50 000		
	FILL & TEST, ALLOW	1	LS		20 000		
	ROUND-OFF				100		
	TOTAL				144 000		

A-45

NACE CSE 523 (3-80)

PREPARED BY HAJ

CHECKED BY

TYPE OF ESTIMATE Order of Magnitude

ESTIMATE SUMMARY

MDC Water Supply - Merrimac River Diversion
PROJECT

PREPARED FOR

JOB NO. 15322-008

DATE May 1984

SHEET 28 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	DEWATERING						
	Allow for the system (shafts; cavern)	1	LS		500 000		
	NEW 48" ø DIP FROM EXISTING SPOT POND PUMPING STATION TO MDC SYSTEM	14,500	LF	560	8,100,000		

A-46

M&CE CSF 523 (3-80)

ESTIMATE SUMMARY

PREPARED BY: HAJ

CHECKED BY:

TYPE OF ESTIMATE: ORDER OF MAGNITUDE

PROJECT: MDC WATER SUPPLY – MERRIMACK RIVER DIVERSION

PREPARED FOR:

JOB NO.: 15 322 – 008

DATE: MAY 1984

SHEET 29 of 30

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	PIPELINE & CONNECTION TO SPOT POND	1	LS		400,000		

A-47

HACE CSE 523 (3-80)

ESTIMATE SUMMARY

PREPARED BY: HAJ

CHECKED BY:

TYPE OF ESTIMATE: ORDER OF MAGNITUDE

JOB NO.: 15322-008

DATE: 25 MAY 1984

SHEET 30 of 30

PROJECT: MDC WATER SUPPLY - MERRIMACK RIVER DIVERSION

PREPARED FOR:

NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COSTS	AMOUNT	TOTALS	REMARKS
	SHAFT TO RESERVOIR CONNECTION @ FELLS RESERVOIR						
	PIPELINE ϕ 30"	1000	LF	260.00	260 000		
	30" GATE VALVE	1	EA	32 000.00	32 000		
	INLET-OUTLET STRUCTURE ALLOWANCE	1	LS	5000.00	5 000		
	8" VENT PIPE AT SHAFT #8	20	FT	40.00	800		
	ROUND OFF				2 200		
	TOTAL					300 000	

A-48

H&CF CSE 523 (3-80)

ESTIMATING WORKSHEET

CLIENT MERRIMACK R. ALTERNATIVE
PROJECT & LOCATION MDC WSS

PREPARED BY: N. D. ZEIGLER
CHECKED BY: J. L. Randz

SHEET 1 OF 4
DATE 4/1/85

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST ENERGY ($/yr)	LABOR ($/yr)	MATERIALS ($/yr)	CHEM	WST DISPOS	(illegible)
	O&M - SUMMARY									
	RAW WATER INTAKE & PUMPING FACILITY				INCL. W/WTP COST	INCL W/ WTP COST	INCL W/ WTP COST			
	WATER QUALITY MONITORING				INCL W/WTP COST	INCL. W/WTP COST	15000			
	WATER TMT. PLANT				2,040,000	1840,000	870,000	3300,000		
	- WASTE DISPOSAL TUNNEL				—	7,000	2000	450,000		
	UNDERGROUND PUMP STATION				3,200,000	INCL. W/ABOVE GROUND FAC.	55,000			
	ABOVE GROUND FACILITIES AT SPOT POND				250,000	500,000	20000			
	FELLS RES. CONNECTION				—	1000	500			
	CONNECTION TO MDC SHAFT 2A				—	1000	500			
	48" PIPELINE						50000			
	SYSTEM ACQUISITION					70000	30000			
	TOTAL				5490,000	2419,000	1043,000	3750,000		
							3411 1040,000			

IPD 13912 2 81

ESTIMATING WORKSHEET

~~CLIENT~~ MERRIMACK R. ALTERNATIVE
PROJECT & LOCATION MDC WSC

PREPARED BY: N.D. ZEIGLER
CHECKED BY: J.L. Rau

SHEET 2 OF 4
DATE 4/1/85

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST ENERGY ($/yr)	LABOR ($/yr)	MATERIALS ($/yr)	CHEM/WASTE ($/yr)
	WATER TREATMENT PLANT							
	RAW WATER PUMPING STA 4-54,400 gpm, 40' TDH VERTICAL TURBINE PUMPS				697500	84000	43100	
	RAPID MIX TANKS 8-1600 cf CAPACITY TANKS				204000	14400	200	
	FLOCCULATION TANKS 16-ea 50,000 cf CAPACITY				6600	8000	22700	
	SEDIMENTATION BASINS 30-ea 150'x75'x15'				29900	324000	87700	
	DUAL MEDIA FILTER STRUCTURE 14-ea WITH 4 CELLS & 676 sf. PER CELL				253400	408000	99300	
	GAC FILTER STRUCTURE 14-ea. WITH 4 CELLS & 676 sf PER CELL.				364400	480000	118700	
	GAC FILTER MEDIA 18,900 ft^3/yr, DENSITY = 26 lb/ft^3				—	—	273800	
	AIR-WATER BACKWASH FACILITIES				86400	10660	14400	

A-50

GPO 13912 2 81

ESTIMATING WORKSHEET

BECHTEL

~~CLIENT~~ MERRIMACK R. ALTERNATIVE
PROJECT & LOCATION MDC WSS

PREPARED BY: N. D. ZEIGLER
CHECKED BY: J. L. Ka[illegible]

SHEET 3 OF 4
DATE 4/1/85

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST ENERGY ($/YR)	LABOR ($/YR)	MATERIALS ($/YR)	CHEM	WASTE DISPOSAL ($/YR)
	SLUDGE THICKENERS 9 - 100φ x 12'				5100	3100	12600		—
	BASKET CENTRIFUGE 2 - TOTAL CAPACITY OF 30,000 gpd				71200	49200	22700		—
	CENTRIFUGE BLDG 120' X 60'				121000	—	—		—
	ADMIN/LAB/MAINT. BLDG. 13,000 sf				56900	192000	24800		—
	CLEARWELL - 1 MG BELOW GROUND				—	—	—		—
	SURGE BASIN - 0.45MG				—	—	—		—
	CHEMICAL FEED SYSTEMS								
	CHLORINE - 5ppm, 10,600 lb/day				1100	9600	8600		39[illegible]000
	LIME - 15ppm; 35,100 T/day 70% purity lime				4500	36000	1600		134200
	ALUM - 30ppm;				10000	1800	200		1,79950[illegible]
	POLYMER - 2ppm TOTAL use 2 units @ 1500 lb/hr ea.				4800	1[illegible]800	4200		77440[illegible]
	SUB TOTAL				274600	301750	75400		3110300

A-51

SD: 3912 2 81

ESTIMATING WORKSHEET

~~CLIENT~~ MERRIMACK R. ALTERNATIVE
PROJECT & LOCATION MDC WSS

PREPARED BY: N. D. ZEIGLER
CHECKED BY: J. L. Forville

SHEET 4 OF 4
DATE 4/1/85

CODE ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL COST ENERGY ($/yr)	LABOR ($/yr)	MATERIALS ($/yr)	CHEM/DISP. WST. ($/yr)
	SLUDGE PUMPS TO THICKENERS; 1390 gpm 30' TDH, 1 STANDBY				5500	5160	10800	
	SLUDGE PUMPS TO CENTRIFUGE 277 gpm, 50' TDH				17600	27600	5800	
	RECYCLE PUMPS, 18.2 MGD 30' TDH, 1 STANDBY				37000	10700	2900	
	OFF-SITE CARBON REGEN. 25 MI HAUL DIST; 4640 FT³ STORAGE				2000	20400	2400	
	AMMONIA FEED SYSTEM 1.7 ppm				1900	10300	7100	84100
	FLUORIDE ADDITION 0.7 ppm AS F⁻ 2300 lb/day Na_2SiF_6				1600	7200	300	104100
	SLUDGE HANDLING TO LANDFILL (20 MI HAUL DIST)				66400	168000	86300	—
	SLUDGE DISPOSAL							450000

SPD 13912 2 81

APPENDIX 8-3

RESULTS OF MDC MODEL RUNS

INTRA-OFFICE MEMO

To: Patricia B. Corcoran, Project Manager

From: Marcis Kempe

Date: 6/8/84

Subject: Hydraulic Analysis of Merrimack Alternative Effects on Distribution System, W79-0749

As we agreed with Bechtel, I ran the Distribution System Model to verify whether the Merrimack Alternative would have an impact on our distribution system and whether additional work on our system was necesary to accomodate the alternative. In the interests of time, I made gross adjustments to demand data to make aggregate demands equal to WFA demands. Therefore, results are approximate only. Runs were made on shutdown of the City Tunnel Extension for construction purposes and the three Bechtel suggested alternatives for tying in the new tunnel. The following is a summary of my conclusions from the model runs:

1. Shutdown of the Shaft 9 to Shaft 9A leg of the City Tunnel Extension is possible under 1990 average day conditions. However, the Spot Pond Pumping Station must supply virtually the entire Northern High Service for the duration and Basins 1, 2 and 3 of the Fells Reservoir must be connected. The Spot Pond Pumping Station's discharge piping may be a limitation.

2. A new pipline connection from Spot Pond Pumping Station to the 60" loop around Shaft 9A would ease the above discharge limitation, raise pressures in the southern half of the Northern High during shutdown and, in the long run, possibly eliminate the Fells pumping from Spot Pond when the Merrimack alternative is not operating.

3. Shutdown of the entire City Tunnel Extension from Shaft 7 to Shaft 9A is possible only for as long as Spot Pond storage lasts. It is not possible to supply Spot Pond from the Weston Aqueduct Supply Mains and keep up suction pressures for the Northern Extra High and Intermediate High at the same time.

4. A decision on how to control the Merrimack Alternative is necessary. The following are the choices:

    A. Pump to demand and vary the water treatment plant to meet demand.

    B. Treat and Pump at a constant rate and use distribution system storage to store excess when necessary. 1990 Average day demands appear to be less than 250 mgd at night which means that under option B, either Fells, Spot Pond or Norumbega must be able to absorb excess and then return it during the day. Fells storage is limited and pushing the water into Norumbega would raise system pressures to levels that may cause problems (to both MDC and user communities). Venting to Spot Pond appears to be the best means of storage for Option B which means that the proposed pump station should include pumps to return the water to service from Spot Pond. My feeling is that Option B may be more workable than A because of the problems in varying treatment rates and matching treatment rates to pumping rates without storage.

5. All three of the Bechtel alternates for making a connection into the distribution system will work. The tunnel to tunnel connection is the obvious choice, due to the reduced head loss. Future operation will require throttling the valves below Norumbega Reservoir or at Shaft 5 or at Shaft 7 to reduce the area served by Norumbega Reservoir and allow the slightly lower gradient from the Merrimack pumping station to push water into the system. The Boston Low should also be switched from Weston Reservoir to Shaft 7 when Merrimack is in operation. Potential velocities of over 20 FPS through the Shaft 9 valve are also a concern.

6. Since a large part of the head loss from the Spot Pond area into the system was in the 10' tunnel from Spot Pond to Shaft 9A, I tried increasing the tunnel size to 12'. I also tried reducing the head loss across the Shaft 9 to Shaft 9A section with a parallel tunnel. Although these options increased the flow capacity into the system, they don't appear necessary. The 10' tunnel apperas to be capable of putting the 250 mgd into the system along with additonal flow from storage if necessary. By manipulating the throttling of Norumbega Reservoir, it should be possible to maintain adequate system pressures.

7. There are still problems to consider including such items as surge control, effects of rapid shutdown, chemical feed startup and waste of stagnant water often shutdown, siting chemical feed, revisions to existing chemical feed at Shaft 4, revisions to Bear Hill pumping from Spot Pond, effects of pumping into Northern Low (closed system), potential for infiltration into supply tunnel, possible quality degradation in Spot Pond, rebuilding Fells Reservoir intake including larger chemical feed, suitability of Shaft 5 valves for throttling, clearwell sizing at the treatment plant to allow for fluctuations in pumping verses water production; possible flow reversals in community distribution systems, etc.

A more detailed discussion is enclosed.

MK/kad

cc: F. Matchener, Bechtel
R. Sharpin, WFA

APPENDIX 8-4

UNIT COST CALCULATIONS

24440.14.14.BCM

Bechtel Civil & Minerals, Inc.
15740 Shady Grove Road
Gaithersburg, Maryland 20877-1454
301-258-3000

RECEIVED
MAY 09 1985
WALLACE, FLOYD, ASSOCIATES INC

May 6, 1985
BLO:063
File: 3.8, 11.8

Ms. Pamela W. McNamara
Arthur D. Little, Inc.
25 Acorn Park
Cambridge, Massachusetts 02140

Dear Pam:

Subject: Bechtel Job 15322
MDC Water Supply Study and EIR
Visicalc Sheet for Merrimack River Alternative

We have revised our design and cost estimates for the Merrimack River Alternative to reflect MDC's comments.

Enclosed are revised Visicalc sheets for this alternative. One sheet represents the costs of building the alternative in three stages. The other sheet represents the costs of building it all at once.

If there are any questions, feel free to contact us.

Very truly yours,

Frank W. Matchner III
Project Engineer

FWM:dek
Enclosures

cc: H. R. Strieder (WFA) w/2 copies

FILE:MERR1_1.WC MERRIMACK RIVER ALTERNATIVE ECONOMIC DATA

ANNUAL Year		OPERATION Labor	and Energy	MAINTENANCE Materials	COSTS. Chem./Waste	in 1982 Replace	dollars Total'82 $	Inflated current $	Present Value $	CAPITAL 1982 $	COSTS Inflated current $	Present Value $	CAPITAL and O&M Present Value $	WATER YIELD Maximum
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	3	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	0	0	0	0	0	164643333.33	215182251.99	146449425	146449425	0
1988	6	0	0	0	0	0	0	0	0	164643333.33	227017275.85	143059392.02	143059392.02	0
1989	7	0	0	0	0	0	0	0	0	164643333.33	239503226.02	139747832.02	139747832.02	0
1990	8	2419000	5490000	1040000	3750000	1900000	14599000	22404888.432	12104664.0808	0	0	0	12104664.0808	43800
1991	9	2419000	5490000	1040000	3750000	1900000	14599000	23637157.296	11824463.5234	0	0	0	11824463.5234	43800
1992	10	2419000	5490000	1040000	3750000	1900000	14599000	24937200.948	11550749.0899	0	0	0	11550749.0899	43800
1993	11	2419000	5490000	1040000	3750000	1900000	14599000	26308747	11283370.6388	0	0	0	11283370.6388	43800
1994	12	2419000	5490000	1040000	3750000	1900000	14599000	27755728.085	11022181.5036	0	0	0	11022181.5036	43800
1995	13	2419000	5490000	1040000	3750000	1900000	14599000	29282293.129	10767038.4133	0	0	0	10767038.4133	43800
1996	14	2419000	5490000	1040000	3750000	1900000	14599000	30892819.251	10517801.413	0	0	0	10517801.413	43800
1997	15	2419000	5490000	1040000	3750000	1900000	14599000	32591924.31	10274333.7877	0	0	0	10274333.7877	43800
1998	16	2419000	5490000	1040000	3750000	1900000	14599000	34384480.147	10036501.987	0	0	0	10036501.987	43800
1999	17	2419000	5490000	1040000	3750000	1900000	14599000	36275626.555	9804175.5521	0	0	0	9804175.5521	43800
2000	18	2419000	5490000	1040000	3750000	1900000	14599000	38270786.016	9577227.044	0	0	0	9577227.044	43800
2001	19	2419000	5490000	1040000	3750000	1900000	14599000	40375679.247	9355531.9735	0	0	0	9355531.9735	43800
2002	20	2419000	5490000	1040000	3750000	1900000	14599000	42596341.605	9138968.7334	0	0	0	9138968.7334	43800
2003	21	2419000	5490000	1040000	3750000	1900000	14599000	44939140.394	8927418.5312	0	0	0	8927418.5312	43800
2004	22	2419000	5490000	1040000	3750000	1900000	14599000	47410793.115	8720765.3245	0	0	0	8720765.3245	43800
2005	23	2419000	5490000	1040000	3750000	1900000	14599000	50018386.737	8518895.7568	0	0	0	8518895.7568	43800
2006	24	2419000	5490000	1040000	3750000	1900000	14599000	52769398.007	8321699.0958	0	0	0	8321699.0958	43800
2007	25	2419000	5490000	1040000	3750000	1900000	14599000	55671714.898	8129067.1722	0	0	0	8129067.1722	43800
2008	26	2419000	5490000	1040000	3750000	1900000	14599000	58733659.217	7940894.321	0	0	0	7940894.321	43800
2009	27	2419000	5490000	1040000	3750000	1900000	14599000	61964010.474	7757077.3229	0	0	0	7757077.3229	43800
2010	28	2419000	5490000	1040000	3750000	1900000	14599000	65372031.05	7577515.3478	0	0	0	7577515.3478	43800
2011	29	2419000	5490000	1040000	3750000	1900000	14599000	68967492.758	7402109.8999	0	0	0	7402109.8999	43800
2012	30	2419000	5490000	1040000	3750000	1900000	14599000	72760704.859	7230764.7634	0	0	0	7230764.7634	43800
2013	31	2419000	5490000	1040000	3750000	1900000	14599000	76762543.627	7063385.9494	0	0	0	7063385.9494	43800
2014	32	2419000	5490000	1040000	3750000	1900000	14599000	80984483.526	6899881.645	0	0	0	6899881.645	43800
2015	33	2419000	5490000	1040000	3750000	1900000	14599000	85438630.12	6740162.1625	0	0	0	6740162.1625	43800
2016	34	2419000	5490000	1040000	3750000	1900000	14599000	90137754.777	6584139.8902	0	0	0	6584139.8902	43800
2017	35	2419000	5490000	1040000	3750000	1900000	14599000	95095331.289	6431729.2446	0	0	0	6431729.2446	43800
2018	36	2419000	5490000	1040000	3750000	1900000	14599000	100325574.51	6282846.6232	0	0	0	6282846.6232	43800
2019	37	2419000	5490000	1040000	3750000	1900000	14599000	105843481.108	6137410.3588	0	0	0	6137410.3588	43800
2020	38	2419000	5490000	1040000	3750000	1900000	14599000	111664872.569	5995340.6745	0	0	0	5995340.6745	43800
TOTAL	xxxxxxxxxx	74989000	170190000	32240000	116250000	58900000	452569000	xxxxxxxxxx	269918111.82	493930000	xxxxxxxxxx	429256649.04	699174760.86	1357800
RESIDUAL VALUE	xxxxxxxxxx	xxxxxxxxx

Enter capital cost:	Phase 1 : 493930000	Phase 2 : 0	Phase 3 : 0
Annual amortize capital cost	57342261.464	0	0

FINANCIAL DATA

Actual	CAPITAL COST Amortized current $	CAPITAL and O&M Current $	COSTS Present Value $
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	57342261.464	57342261.464	39026179.632
0	57342261.464	57342261.464	36135351.511
0	57342261.464	57342261.464	33458658.807
21900	57342261.464	79747149.896	43084903.717
22448	57342261.464	80979418.76	40509870.594
22995	57342261.464	82279462.411	38111311.192
23543	57342261.464	83651008.464	35876483.696
24090	57342261.464	85097989.549	33793582.483
24638	57342261.464	86624554.593	31851668.95
25185	57342261.464	88235080.715	30040607.465
25733	57342261.464	89934185.774	28351006.058
26280	57342261.464	91726741.611	26774161.497
26828	57342261.464	93617888.019	25302008.431
27375	57342261.464	95613047.48	23927072.303
28196	57342261.464	97717940.711	22642425.732
29018	57342261.464	99938603.069	21441648.139
29839	57342261.464	102281401.858	20318788.351
30660	57342261.464	104753054.579	19268329.973
31481	57342261.464	107360648.201	18285159.32
32303	57342261.464	110111659.471	17364535.728
33124	57342261.464	113013976.361	16502064.0542
33945	57342261.464	116075920.681	15693669.2117
34766	57342261.464	119306271.938	14935572.592
35588	57342261.464	122714292.514	14224270.2266
36409	57342261.464	126309754.222	13556512.5655
37230	57342261.464	130102966.323	12929285.75
38051	57342261.464	134104805.09	12339794.2704
38873	57342261.464	138326744.99	11785444.9052
39694	57342261.464	142780891.58	11263831.8478
40515	57342261.464	147480016.24	10772722.9322
41336	0	95095331.289	6431729.2446
42158	0	100325574.51	6282846.6232
42979	0	105843481.108	6137410.3588
43800	0	111664872.569	5995340.6745
990980	1720267843.9	xxxxxxxxxx	744414248.83

Enter res.val:	444540000	3400198811.7	182558308.34 PV-res value	
xxxxxxxxxxxxx			561855940.49	- Total pv-res pv
521.31874762 NPV/Actual M6 unit cost	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx		566.97000998	- NPV/Actual M6

FILE:MERRI_2.VC MERRIMACK RIVER ALTERNATIVE ECONOMIC DATA

ANNUAL OPERATION and MAINTENANCE COSTS, in 1982 dollars CAPITAL COSTS CAPITAL and O&M WATER YIELD

Year		Labor	Energy	Materials	Chem./Waste	Replace	Total'82 $	Inflated current $	Present Value $	1982 $	Inflated current $	Present Value $	Present Value $	Maximum
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	3	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	5	0	0	0	0	0	0	0	0	153766666.67	200966883.65	136774684.17	136774684.17	0
1988	6	0	0	0	0	0	0	0	0	153766666.67	212020062.25	133608603.522	133608603.522	0
1989	7	0	0	0	0	0	0	0	0	153766666.67	223681165.68	130515811.774	130515811.774	0
1990	8	2070000	3240000	760000	1880000	1600000	9550000	14656256.2182	7918319.198	0	0	0	7918319.198	31390
1991	9	2070000	3300000	760000	1930000	1600000	9660000	15640450.6803	7824119.2983	0	0	0	7824119.2983	31390
1992	10	2070000	3350000	760000	1970000	1600000	9750000	16654408.4689	7714213.5507	0	0	0	7714213.5507	31390
1993	11	2070000	3410000	760000	2020000	1600000	9860000	17768631.099	7620661.3123	0	0	0	7620661.3123	31390
1994	12	2070000	3460000	760000	2060000	1600000	9950000	18917014.483	7512206.7238	0	0	0	7512206.7238	31390
1995	13	2070000	3520000	760000	2110000	1600000	10060000	20178085.409	7419440.1286	0	0	0	7419440.1286	31390
1996	14	2070000	3580000	760000	2160000	1600000	10170000	21520650.167	7326942.9666	0	0	0	7326942.9666	31390
1997	15	2070000	3630000	760000	2200000	1600000	10260000	22905208.81	7220677.078	0	0	0	7220677.078	31390
1998	16	2070000	3690000	760000	2250000	1600000	10370000	24424074.192	7129154.4356	0	0	0	7129154.4356	31390
1999	17	2070000	3740000	760000	2290000	1600000	10460000	25991030.466	7024568.551	0	0	0	7024568.551	31390
2000	18	2070000	3800000	760000	2340000	1600000	10570000	27708898.431	6934124.9301	0	0	0	6934124.9301	31390
2001	19	2070000	3880000	760000	2410000	1600000	10720000	29647734.881	6869737.8421	0	0	0	6869737.8421	31390
2002	20	2070000	3970000	760000	2480000	1600000	10880000	31745201.498	6810876.075	0	0	0	6810876.075	31390
2003	21	2070000	4050000	760000	2550000	1600000	11030000	33952922.703	6744943.2427	0	0	0	6744943.2427	31390
2004	22	2070000	4140000	760000	2620000	1600000	11190000	36339939.377	6684386.8745	22400000	72744829.494	13380720.8212	20065107.696	31390
2005	23	2270000	4220000	900000	2690000	1800000	11880000	40702680.624	6932288.6219	0	0	0	6932288.6219	37778
2006	24	2270000	4310000	900000	2760000	1800000	12040000	43519662.443	6863021.927	0	0	0	6863021.927	37778
2007	25	2270000	4390000	900000	2830000	1800000	12190000	46485252.73	6787679.2129	0	0	0	6787679.2129	37778
2008	26	2270000	4480000	900000	2900000	1800000	12350000	49685642.258	6717586.4693	0	0	0	6717586.4693	37778
2009	27	2270000	4560000	900000	2970000	1800000	12500000	53055012.735	6641788.2414	0	0	0	6641788.2414	37778
2010	28	2270000	4650000	900000	3050000	1800000	12670000	56734271.758	6576280.5299	0	0	0	6576280.5299	37778
2011	29	2270000	4730000	900000	3120000	1800000	12820000	60563275.372	6500106.0975	0	0	0	6500106.0975	37778
2012	30	2270000	4810000	900000	3190000	1800000	12970000	64641848.21	6423934.4462	17400000	86720752.418	8618077.052	15042011.4983	37778
2013	31	2420000	4900000	1040000	3260000	2000000	13620000	71614894.458	6589719.613	0	0	0	6589719.613	43800
2014	32	2420000	4980000	1040000	3330000	2000000	13770000	76385803.011	6508073.8579	0	0	0	6508073.8579	43800
2015	33	2420000	5070000	1040000	3400000	2000000	13930000	81523490.066	6431293.8505	0	0	0	6431293.8505	43800
2016	34	2420000	5150000	1040000	3470000	2000000	14080000	86933323.327	6350071.2141	0	0	0	6350071.2141	43800
2017	35	2420000	5240000	1040000	3540000	2000000	14240000	92756868.111	6273568.3569	0	0	0	6273568.3569	43800
2018	36	2420000	5320000	1040000	3610000	2000000	14390000	98889308.665	6192901.0828	0	0	0	6192901.0828	43800
2019	37	2420000	5410000	1040000	3680000	2000000	14550000	105488228.654	6116810.7898	0	0	0	6116810.7898	43800
2020	38	2420000	5490000	1040000	3750000	2000000	14700000	112437401.655	6036818.1325	0	0	0	6036818.1325	43800
TOTAL	xxxxxxxxxxx	68570000	132470000	26920000	84820000	54400000	367180000	xxxxxxxxxxx	212696314.65	501100000	xxxxxxxxxxx	422897897.34	635594211.99	1123474
RESIDUAL VALUE	xxxxxxxxxxx	xxxxxxxxxx

	Phase 1 :	Phase 2 :	Phase 3 :
Enter capital cost:	461300000	22400000	17400000
Annual amortize capital cost	53554117.412	7974974.3019	13158514.5273

0

FINANCIAL DATA

Actual	CAPITAL COST Amortized current $	CAPITAL and O&M Current $	COSTS Present Value $
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	53554117.412	53554117.412	36448032.443
0	53554117.412	53554117.412	33748178.188
0	53554117.412	53554117.412	31248313.137
21900	53554117.412	68210373.63	36851942.473
22448	53554117.412	69194568.092	34614511.219
22995	53554117.412	70208525.881	32520131.996
23543	53554117.412	71322748.511	30589104.317
24090	53554117.412	72471131.895	28779283.58
24638	53554117.412	73732202.821	27111177.959
25185	53554117.412	75074767.579	25560033.55
25733	53554117.412	76459326.222	24103168.359
26280	53554117.412	77978191.604	22761090.807
26828	53554117.412	79545147.878	21498583.709
27375	53554117.412	81263015.843	20335990.818
28196	53554117.412	83201852.293	19278872.923
29018	53554117.412	85299318.91	18300815.965
29839	53554117.412	87507040.115	17383776.474
30660	61529091.714	97869031.091	18002079.202
31481	61529091.714	102231772.338	17411633.369
32303	61529091.714	105048754.157	16566118.9154
33124	61529091.714	108014344.444	15772028.2762
33945	61529091.714	111214733.972	15036428.1945
34766	61529091.714	114584104.449	14344419.4684
35588	61529091.714	118263363.472	13708346.4809
36409	61529091.714	122092367.086	13103870.8669
37230	74687606.241	139329454.45	13846189.529
38051	74687606.241	146302500.7	13462178.023
38873	74687606.241	151073409.25	12871461.2746
39694	74687606.241	156211006.31	12323319.2363
40515	74687606.241	161620929.57	11805650.275
41336	21133488.829	113890356.941	7702922.2096
42158	21133488.829	120022797.494	7516376.8722
42979	21133488.829	126621717.483	7342251.3356
43800	21133488.829	133570890.485	7171485.3945
990980	1860624716.2	xxxxxxxxxxx	679119766.75

Enter res.val:	451000000	3449610078	185211222.98 PV-res value
xxxxxxxxxxxxxx			493908543.77 - Total pv-res pv
454.48242045 NPV/Actual MG unit cost	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx		498.4041492 - NPV/Actual MG

APPENDIX 8-5

ANALYSIS OF TUNNEL VS. PIPELINE

MERRIMACK RIVER ALTERNATIVE -TUNNEL VS. PIPELINE

In Phase I of the MDC Water Supply Study, the Merrimack River Alternative was designed to provide 125 MGD of water to the MDC system for certain months of the year. The average annual yield of the alternative was 70 MGD. In Phase II, the average annual yield is set at 120 MGD. To provide that yield, the actual transfer rate would be approximately 250 MGD.

In Phase I, a 72" diameter pipeline, 30 miles long, was considered for conveying water to the MDC system. Now, at the increased transfer rate, the conduit would be on the order of 120" (10 feet) in diameter. Considering the difficulties and impacts associated with installing 30 (now closer to 32) miles of pipeline of this size, a tunnel seems to be a more practical choice than a pipeline.

Order-of-magnitude costs were estimated for both the pipeline and the tunnel. Table 1 presents those estimates. Only pertinent elements of the total cost for this alternative were considered. Those are the elements that would be different for a tunnel and a pipeline. For example, the cost of water treatment and pumping are excluded from the estimates because they are the same for the tunnel as for the pipeline.

Costs presented for the tunnel option include costs of the tunnel, shafts and spoil disposal. Costs presented for the pipeline option include costs of the pipeline; standpipe; blow offs; air relief valves; thrust blocks; anti-flotation collars; highway, river, railroad and utility crossings; street repair; clearing and grubbing; construction access roads; and right-of-way acquisition. Other elements of the total construction cost would be common to both options.

Table 1 indicates that the present value of the costs associated with the tunnel option are about 17 percent more than those associated with a pipeline. Conventional drill and blast technology has been assumed for the tunnel installation after reviewing the limited geological information available for this region of the state. If for some sections of the tunnel, a tunnel boring machine can be used, some cost savings would be expected.

While the tunnel appears to be about 17 percent more expensive than a pipeline, the tunnel option has several advantages over the pipeline option. Those are:

- The tunnel is expected to have a longer service life and to require less maintenance and repair. (We have tried to reflect these differences in the estimated operating, maintenance and replacement costs.)

- o Right-of-way acquisition is greatly simplified if a tunnel is used. Costs are included under the pipeline option for acquisition of 250 acres of land (80' wide by 25 miles long) at an average price of $5,000 per acre. Part of the alignment is assumed to follow public rights-of-way (Route 93, etc.) at no cost. The Massachusetts DPW has indicated some reluctance to allowing high pressure force mains within the rights-of-way of state (and federal) highways. Alternate alignments may prove to be longer and more costly, and may require a substantial amount of time to acquire.

- o There are numerous uncertainties associated with the pipeline option related to: the extent of rock excavation required (maybe 30 percent or more of the alignment is through rock); problems associated with installations in marshy areas and crossing the Concord and Aberjona Rivers; problems and costs associated with railroad and road crossings; and problems associated with supporting, repairing and relocating existing utilities which interfere with the pipeline alignment.

- o Most of the impacts associated with installation and maintenance of the pipeline are eliminated if a tunnel is used. Some of those impacts include:

  - impacts on traffic
  - impacts associated with dust and noise generated by surface blasting, excavation and backfilling to install the pipeline (32 miles long)
  - impacts on wetlands and other ecological sensitive areas
  - impacts on utility services during shutdowns for repairs and relocations.

- o The tunnel option allows for gravity flow for most of the distance between Tyngsborough and Medford. Hydraulic transients are greatly reduced if the flow is by gravity. Also, operation and maintenance are greatly simplified if the flow is by gravity in a tunnel, instead of pressure flow in a pipeline. Also, because the pipeline is pressurized and subject to expansion and contraction, settlement and lateral movement, the chance for leakage in the pipeline is more prominent.

- o Construction of a pipeline would be more susceptible to potential delays due to bad weather, public opposition, right-of-way acquisition, special permitting requirements (wide load permits for pipeline sections), unexpected subsurface conditions, and utility relocations.

- o The tunnel would have a higher degree of flexibility than a pipeline in carrying higher flow rates and higher pressures without future modification. This would allow the flexibility to transfer at higher rates, if needed, in future years.

We believe that when considering each of these advantages, that the tunnel is a more practical choice than a pipeline. We also believe that choosing a tunnel for the Merrimack River Alternative makes its design more consistent with the two other major water supply alternatives being studied (the Connecticut River Alternative and the Millers/Tully River Alternative).

TABLE 1: ESTIMATED COSTS OF TUNNEL AND PIPELINE[1]

	Tunnel	Pipeline
Estimated Construction Cost	$ 220,000,000	$ 170,000,000
Estimated Total Capital Cost [2]	$ 315,000,000	$ 243,000,000
Residual Value at Year 2020 (Inflated)	$2,168,000,000	$1,673,000,000
Present Worth of Residual Value [3,4]	$ 116,000,000	$ 90,000,000
Net Present Worth of Capital Costs	$ 199,000,000	$ 153,000,000
Operating, Maintenance and Replacement Cost (OM&R) [5]	$ 315,000/yr	$ 1,215,000/yr
Present Worth of 30 years of OM&R [4]	$ 5,800,000	$ 22,500,000
Present Value of All Costs (Line 4 + Line 6)	$204,800,000	$175,500,000
Difference	$29,300,000	
Percent Increase (Tunnel over Pipeline)	17%	

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1 All costs in 1982 dollars.

2 Total capital cost includes contractor's overhead and profit, engineering fees, etc. on tunnel and pipeline elements of the total cost; but excludes costs for other elements such as water treatment and pumping facilities.

3 Residual value is the assessed value of the facilities after 30 years of operation (1990 to 2020).

4 Based on 5.5 percent inflation rate and 8.0 percent discount rate.

5 OM&R based on cost curves developed by the U. S. Army Corps of Engineers.

APPENDIX 8-6

TECHNICAL APPENDIX ON WATER QUALITY
FOR
TASK 8: MERRIMACK RIVER ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.

APPENDIX 8-7

TECHNICAL APPENDIX ON AQUATIC ECOLOGY
FOR
TASK 8: MERRIMACK RIVER ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.

APPENDIX 8-8

TECHNICAL APPENDIX ON TERRESTRIAL ECOLOGY
FOR
TASK 8: MERRIMACK RIVER ALTERNATIVE

Published Under Separate Cover

Prepared By:

Normandeau Associates, Inc.